FINAL REPORT

SULLIVAN LAKE FEASIBILITY STUDY

Submitted To:

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EXECUTIVE SUMMARY

International Science & Technology, Inc. (IS&T) has provided technical services to the Sullivan County Park and Recreation District in conducting a Feasibility/Design study of Sullivan Lake. The project was conducted under a grant from the Indiana Department of Natural Resources (IDNR) "T by 2000" Lake Enhancement Program (LEP). The primary and most obvious problem addressed during this study was shoreline erosion, however all elements of Feasibility Studies conducted under the LEP, including trophic classification, watershed modeling, and field measurements of water quality were conducted. In addition, the Feasibility Study was designed to quantify the shoreline erosion problem, and to recommend alternative solutions. The objectives of the Design component of the project were to develop bid-ready plans and related specifications for shoreline stabilization control measures on selected areas of the shoreline.

The specific goals of the Feasibility Study were to:

- Assess the current condition of the lake system and establish a baseline against which future changes can be measured.
- Identify potential threats to the well-being of the system, both in the lake and in the watershed.
- Develop mitigative strategies that have the greatest probability of success in improving the overall quality of the lake, and in particular, the lakeshore.

In pursuit of these goals, IS&T implemented a four part program. First, all relevant background information (e.g., resource maps, soil manuals, fisheries studies) was gathered and reviewed to understand the physical setting and to assess the availability of previous research. Second, a lake survey was conducted to collect data on water quality, sediment quality, phytoplankton abundance, and aquatic macrophyte distribution. This also included a detailed shoreline survey, during which data were collected to document the extent of existing shoreline erosion. Third, a watershed survey was completed to identify upland activities resulting in excessive soil erosion and sediment/nutrient transport to the lake. Finally, a program for implementing mitigative strategies was developed to address the identified problems.

Based on the results of the watershed analysis, lake and tributary sampling, and visual observations, the primary source of sediment and nutrient loading to Sullivan Lake was identified as the Morrison Creek drainage basin. However, a wetland at the north end of the lake greatly reduces the impact of non-point source pollutants generated within this sub-basin.

The shoreline survey, conducted in the fall of 1989, documented 14,600 linear feet of shoreline that is currently in an eroded condition. Both vegetative and structural approaches to mitigating shoreline erosion are presented. Specific recommendations include willow planting along the majority of the shoreline, with structural controls (rock revetments and bulkheads) as alternatives in severely eroded areas.

The results of the in-lake and watershed study indicate that Sullivan Lake is experiencing moderate sedimentation and eutrophication. The primary thrust of management efforts should be directed at controlling sediment and nutrient production in the watershed. In-lake restoration measures are not deemed necessary, however limited dredging and or macrophyte harvesting may be necessary in the future. A general, integrated program for managing Sullivan Lake should include application of: (1) appropriate best management practices (BMPs) in the watershed, especially near stream corridors and at animal waste facilities; (2) effective waste water treatment and septic system maintenance at lake shore residences; and (3) effective runoff management at the Sullivan Lake Park and Campground facilities. The Sullivan Lake Park and Recreation District should work with the Soil and Water Conservation District and the Soil Conservation Service to encourage the implementation of BMPs, especially in the critical areas identified in this report. SCS is the agency that is responsible for coordinating BMP applications and will provide free advice to landowners on appropriate strategies and designs.

The bid documents submitted separately with this report and the related drawings and specifications are the results of the Design component of the project. These plans and documents will allow the Sullivan Lake Park and Recreation District to proceed with shoreline stabilization. Sullivan County and the Lake Enhancement Program office should be consulted regarding financial assistance for these measures.

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SECTION 1. INTRODUCTION

This report is the outcome of a Feasibility Study conducted on Sullivan Lake by International Science & Technology, Inc. (IS&T) for the Sullivan County Park and Recreation District. The project was performed and funded under the provisions of the State of Indiana "T by 2000" Lake Enhancement Program (LEP). The LEP was established to ensure the continued viability of Indiana's public access lakes by controlling sediment related problems such as erosion and nutrient enrichment. The objectives of Feasibility studies conducted under this program are to characterize the lake and surrounding watershed, identify water quality related problems, present alternative solutions, and recommend the most appropriate restoration strategies. The ultimate objective of the program is to restore the well being of the lakes through development of specific plans of action for restoration (Design Phase) and installation of the required control measure(s) (Construction Phase or Land Treatment).

1.1 SULLIVAN LAKE

Located in Sullivan County, IN, Sullivan Lake is a 507 acre reservoir situated northeast of the city of Sullivan (Figure 1). Sullivan Lake has a maximum depth of 25 feet and a mean depth of 10 feet, with bottom sediments consisting of gravel, sand and clay (IDNR, 1988). The reservoir was created in the spring of 1969 by the impoundment of Morrison Creek, under Public Law 566, for flood control and conservation measures. The primary tributary to Sullivan Lake is Morrison Creek, entering from the northwest. The spillway discharges to the south, into Busseron Creek. Prior to impoundment, the creek was bordered by a narrow strip of bottom land which frequently flooded. The surrounding topography consisted of moderate to extremely steep, short slopes (USDA, 1971).

Use of Sullivan Lake is primarily recreational. The Sullivan County Park is a 400-acre tract of land on the southwest shore of the reservoir that is heavily used during the summer season. The Park offers many recreational opportunities including picnicking, swimming, golfing, hiking trails and approximately 400 campsites accommodating both primitive camping and full hook-up trailer sites. Boat launching facilities are also available at the Park. The remaining Sullivan Lake shoreline consists of residential development and farmland.

The primary recreational uses of the reservoir include fishing, boating and water skiing. More than 3 million people live within 100 miles of Sullivan Lake. Although weekday use of the reservoir is largely by county resident and lakeshore property owners, residents of Terra Haute, Vincennes, Bloomington and surrounding areas visit Sullivan Lake in large numbers on the weekends (Sullivan County Park and Recreation District., pers. comm.). The majority of the Sullivan Lake anglers surveyed in 1988 by the Indiana Department of Natural Resources (IDNR) were from Sullivan and Vigo Counties in Indiana. Anglers from states other than Indiana constituted the third largest group in the survey. Table 1 documents the origin of the anglers surveyed in 1988.

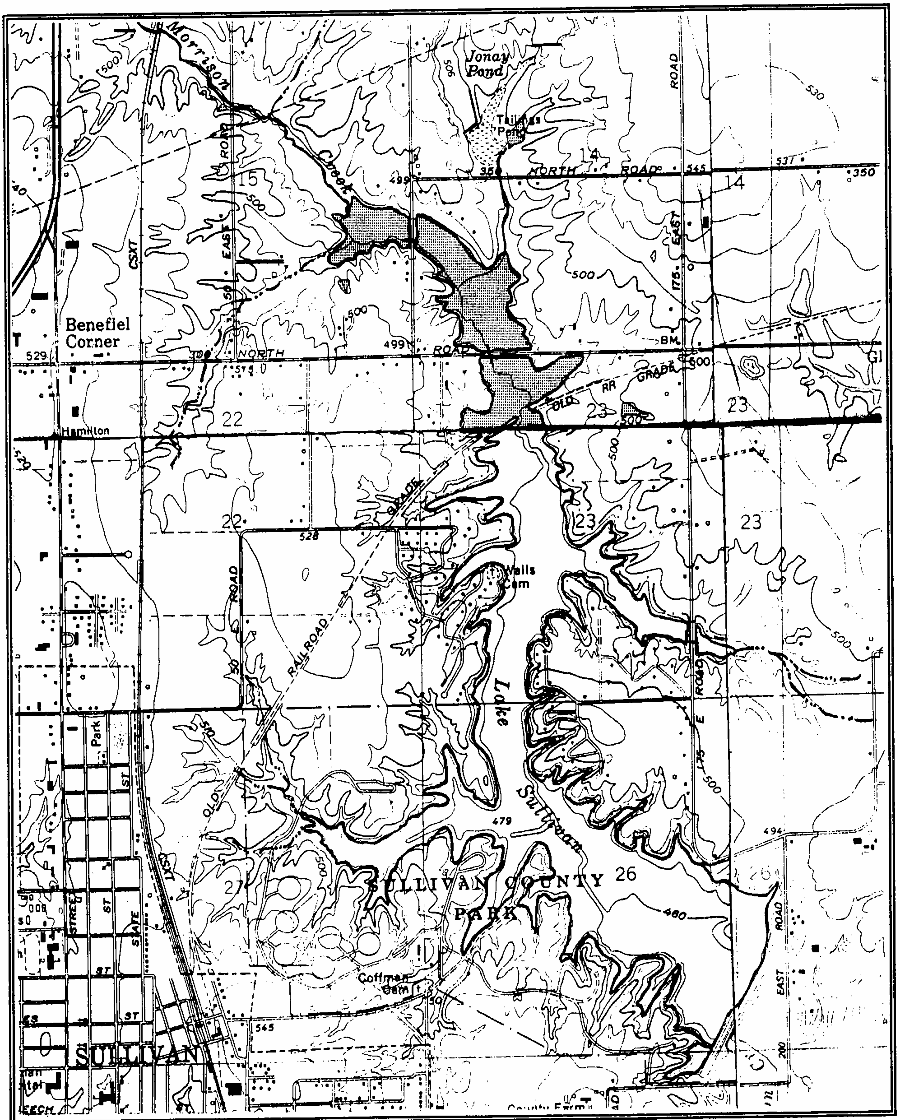

Figure 1. Portions of the USGS Dugger, Sullivan, Hymera and Shelburn quadrangles showing the location of Sullivan Lake.

Table 1. Origin of anglers at Sullivan Lake. (1 April - 31 October 1988)

COUNTY OF RESIDENCE	NUMBER OF PARTIES	COUNTY OF RESIDENCE	NUMBER OF PARTIES
Sullivan	322	Clark	4
Vigo	224	Henry	4
Marion	84	Jackson	4
Knox	77	Parke	4
Greene	75	Bartholomew	3
Lake	60	Fayette	3
Hendricks	31	Grant	3
Gibson	29	Hancock	3
Johnson	24	Noble	3
Newton	21	St. Joseph	3
Clay	19	Shelby	3
Madison	17	Fountain	2
Howard	14	Martin	2
Vanderburgh	13	Miami	2
Vermillion	13	Owen	2
Allen	11	Putnam	2
Daviess	11	Warrick	2
Delaware	10	White	2
Tippecanoe	10	Adams	1
Morgan	9	Benton	1
Porter	9	Cass	1
Jasper	8	Floyd	1
LaPorte	8	Fulton	1
Tipton	7	Marshall	1
Lawrence	6	Randolph	1
Monroe	6	Washington	1
Boone	4		
Sullivan Lake residents	20	Out of State	98

The Sullivan Lake watershed consists of approximately 7632 acres of agricultural, forested and urban land. The principal crop grown in the watershed is corn, and cattle is the primary livestock. Coal mining (deep shaft and slope mines) was a predominant activity in the Sullivan Lake area around the turn of the century. The now-covered entrance to the Sullivan City Coal Company deep mine is located on the grounds of Sullivan County Park, where a memorial was erected to the victims of three local mining disasters. The majority of the acreage east of the Sullivan Lake watershed has seen extensive strip mining for coal deposits. Currently, there are no active strip mining operations within this watershed, however a tailings pond is located north of the reservoir.

Geologically, the Sullivan Lake watershed is composed of Pennsylvanian Age bedrock materials; largely shale, sandstone, coal, clay and limestone. Although the most recent period of glaciation (14,000 - 22,000 years ago) did not reach into the Sullivan County area, evidence of older glaciations have been found. Unconsolidated glacial materials consist of silt in windblown sheet deposits (Clark, 1980).

The soils surrounding Sullivan Lake have been described by the Soil Conservation Service (SCS) as ranging from nearly level to very steep, and well-drained to poorly drained. The two major soil associations found in this area are the Cincinnati-Ava-Alford and the Reesville-Iva Associations.

The Cincinnati-Ava-Alford Association occurs in lands immediately surrounding the reservoir. It is characterized by deep, well-drained to moderately well-drained soils with nearly level to very steep topography. The sloping soils within this association are susceptible to erosion.

The Reesville-Iva Association predominates in the remainder of the drainage basin. This association is characterized by deep, somewhat poorly drained soils with nearly level to gently sloping topography. The sloping soils in this association are also susceptible to erosion.

1.2 NATURE OF THE PROBLEM

The predominant impairment to Sullivan Lake is the extensive bank erosion that has occurred along the entire shoreline of the reservoir. On-site reconnaissance by IS&T during the summer and fall of 1989 indicated advancing erosion in many areas along the main reservoir body. Figure 2 illustrates the nature and severity of this problem. The exposed banks accelerate the erosion process and have led to shoaling and impaired navigation, loss of important near-shore aquatic habitat and decreased property values.

A subtle deterioration in water quality is also evident in Sullivan Lake. In 1986, the reservoir was placed in Trophic Class Two and given a Eutrophication Index (EI) value of 39, out of a possible 75 points, by the Indiana Department of Environmental Management (IDEM) as noted in the Indiana Lake Classification System and Management Plan (1986). This index value was based on data collected at an unknown date prior to 1986 (Harold BonHomme, pers. comm.). Sullivan Lake was surveyed again in 1988 by Indiana University for the IDEM. An evaluation of this data places the reservoir, again, in Trophic Class Two, but gives the reservoir a EI value of 46 (Harold BonHomme, pers. comm.), an increase of 7 points.

Class Two lakes and reservoirs, as described by IDEM, are in an intermediate level of eutrophication, and are usually productive but exhibit subtle trophic changes. Other characteristics include oxygen depletion below the thermocline during stratification, algal blooms during the summer months, and extensive macrophyte concentrations in the bays and littoral areas of the lake. Both IDEM EI values place Sullivan Lake in Lake Management Group VII. Lakes in this group are of intermediate water quality, somewhat shallow (mean depths from 5 - 19.6 ft.), and have EI values from 18 to 54. Management

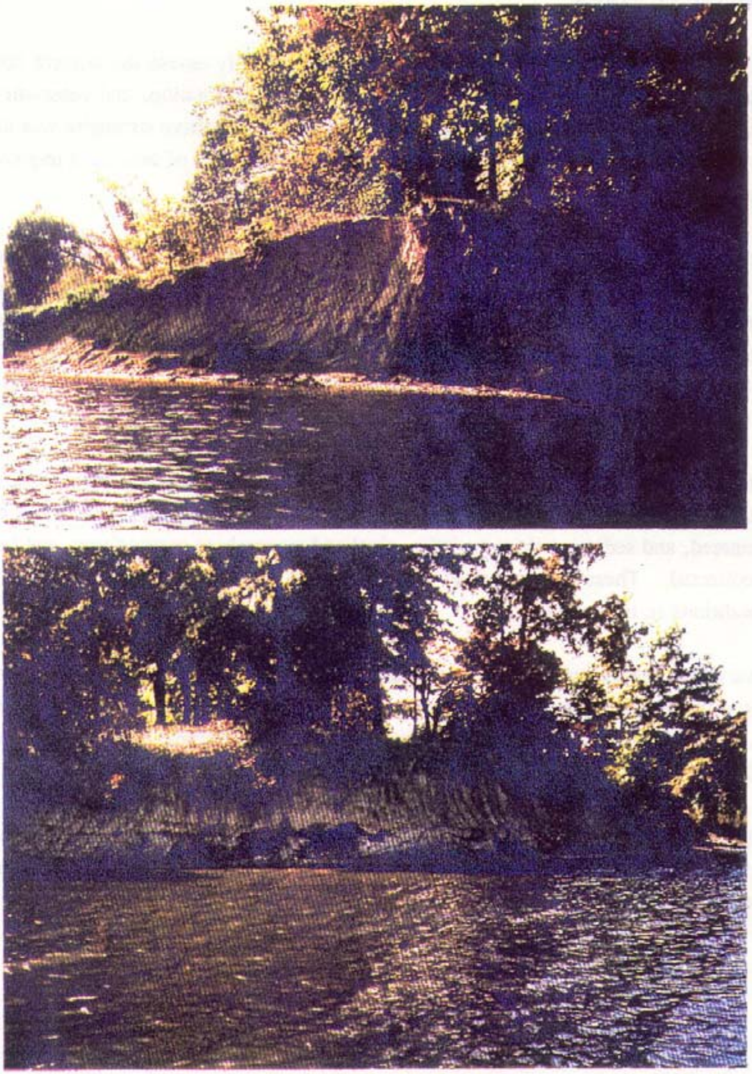

Figure 2. Examples of shoreline erosion at Sullivan Lake in Fall of 1989.

priorities for Group VII lakes focus primarily on water quality improvement through abatement of nutrient inputs, as well as in-lake restoration techniques.

1.3 STUDY OBJECTIVES

The objective of the Sullivan Lake Feasibility Study was to fully assess the current conditions in the reservoir and watershed with respect to shoreline erosion, sedimentation, and reservoir water quality. Based on this assessment, a plan for implementing appropriate mitigative strategies was developed. The mitigative techniques chosen were those having the greatest probability of success in improving the overall quality of the reservoir.

Four phases of activity were necessary to meet the project objectives. First, all relevant information pertaining to the reservoir and watershed (e.g., USGS topographic maps, aerial photographs of the reservoir and watershed, previous water quality and fisheries studies, and hydrologic, geologic and soil data) was collected and reviewed. This information was used to understand the physical setting of the reservoir, and the current status of knowledge regarding erosion, sedimentation and water quality problems.

The second phase of the study involved collection of field data. Water samples and in-situ chemical and physical data were collected from the reservoir. Areas of existing shoreline erosion and bank instability were documented, and sediment characteristics, algal and macrophyte composition, and bathymetric data were also collected. These data provided the most recent evaluation of the chemical, biological and physical conditions in the reservoir.

Thirdly, a survey of the watershed was conducted. Areas of excessive nutrient and sediment loading were identified by using the Agricultural Non-Point Source Pollution (AGNPS) computer simulation developed by the U.S. Department of Agriculture. The watershed survey was critical in addressing problems at their source, and for developing the most appropriate mitigative strategies.

The final phase of this project was to develop recommendations to mitigate the problems observed in this study. The methods used in each phase of the project, and the results of the study are presented in the sections that follow.

SECTION 2. HISTORICAL DATA

The following section describes the historical data collected for this study. This information included water quality data, fishery surveys, soils and land use data, and information from Sullivan County Park. Several state and county agencies, as well as universities, were contacted in pursuit of this information. Additionally, the Sullivan County Park and Recreation District personnel provided observations on the recreational use of the lake and park, as well as the condition of the shoreline. Table 2 presents a summary of the historical data obtained for Sullivan Lake.

Table 2. Sullivan Lake historical data summary.

DATE	AGENCY	DESCRIPTION
198?	Sullivan Co. Park and Recreation Dist.	Description of Park Facilities
198?	IDEM	Newspaper article publicizing park
1985 & 1986	IDNR	Fish Management Report
1988	IDEM	Water Quality Data
1988	IDNR	Fish Management Report
1989	SCS	Soil Survey of Sullivan County, Indiana
1990	Sullivan Co. Park and Recreation Dist.	Correspondence on Recreational Use of Park Facilities

2.1 WATER QUALITY

Table 3 and Figure 3 present a summary of the water quality data collected on Sullivan Lake by Indiana University for the IDEM. The data presented in Table 3 was collected from both the epilimnion and the hypolimnion in July of 1988. Figure 3 presents the dissolved oxygen and temperature profiles in the reservoir on the same sampling date, and indicates a weak thermal stratification with anoxic conditions occurring below two meters (6.5 feet) depth. The Secchi disk transparency of 2.6 feet roughly corresponds to the range of transparencies (1.5 - 2.5 feet) noted in the 1988 IDNR Fish Management Report for Sullivan Lake. A comparison of the total phosphorus (TP) concentrations in the epilimnion and hypolimnion shows a marked increase in the hypolimnetic TP concentration, as would be expected

Table 3. Sullivan Lake historic water quality data. (July 1988 - IDEM)

	Epilimnion	Hypolimnion
Ph	7.4	7.6
Cond.	200	235
NO_3	0.175	0.202
NH_4	0.190	0.992
TON	1.879	1.138
TP	0.292	0.653
SRP	< 0.01	< 0.01

Secchi Disk Transparency: 2.6 ft.

under anoxic conditions. The concentration of total phosphorus in both the epilimnion and hypolimnion is indicative of productive conditions.

2.2 FISH POPULATION SURVEYS

Fish population surveys of Sullivan Lake were conducted in 1985-1986 and 1988 by IDNR. Documented species are listed in Table 4. The 1985-1986 report focused on the evaluation of saugeye and channel catfish stocking programs in Sullivan Lake. Saugeye are the result of a cross between female walleye (Stizostedium vitreum) and male sauger (S. canadense). These fish are more tolerant of the riverine conditions found in reservoirs than are walleye. The saugeye stocking program was initiated in 1983 and the channel catfish (Ictalurus punctatus) stocking began in 1977 in Sullivan Lake. The result of the 1985-1986 fisheries survey indicated that the saugeye stocking program had been very successful. The channel

Table 4. Fish species documented in Sullivan Lake.

COMMON NAME	SCIENTIFIC NAME
Bluegill	Lepomis macrochirus
White Crappie	Pomoxis annularis
Black Crappie	Pomoxis nigromaculatus
Gizzard Shad	Dorosoma cepedianum
Largemouth Bass	Micropterus salmoides
Brown Bullhead	Ictalurus nebulosus
Yellow Bullhead	Ictalurus natalis
Black Bullhead	Ictalurus melas
Channel Catfish	Ictalurus punctatus
White Catfish	Ictalurus catus
Common Carp	Cyprinus carpio
Warmouth	Lepomis gulosus
Redear Sunfish	Lepomis microlophus

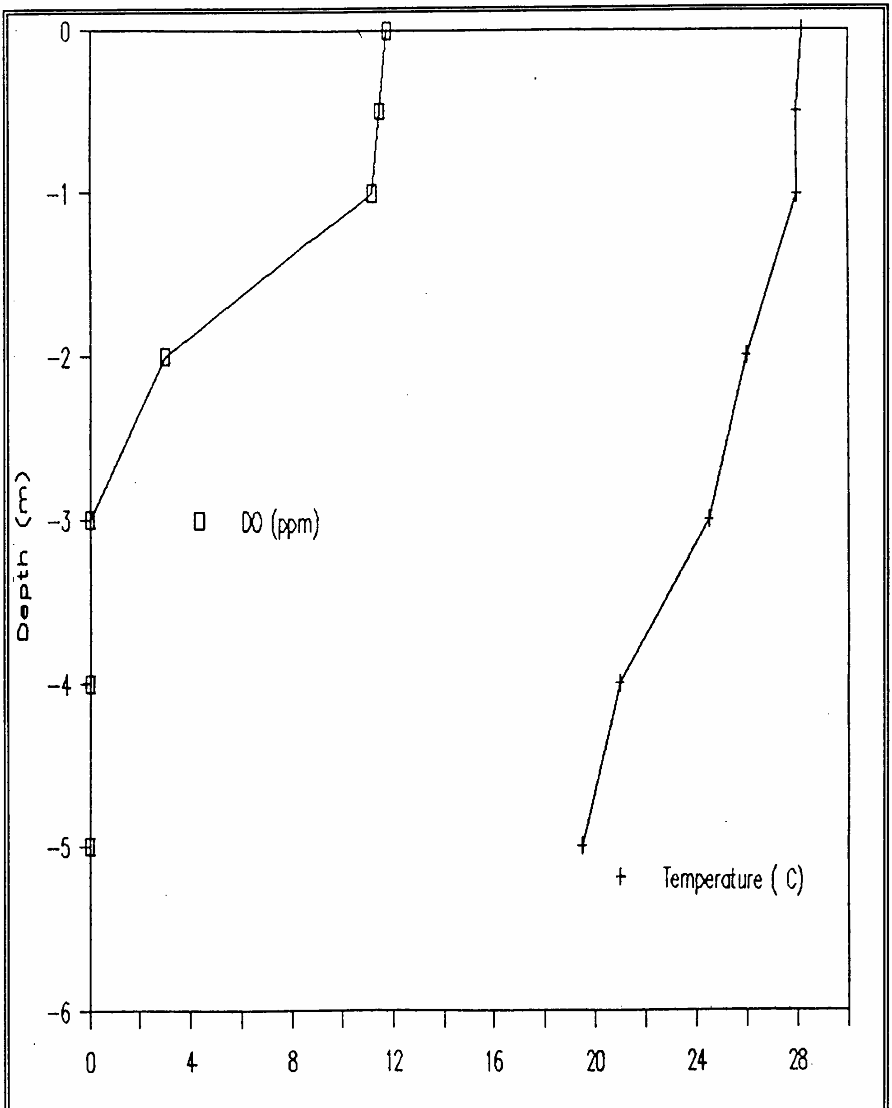

Figure 3. Dissolved oxygen and temperature profiles observed in Sullivan Lake on 8 August 1988.

catfish population, however, was found to exhibit low level recruitment. The survey report recommended a continuation of the saugeye stocking program as well as supplemental stockings of channel catfish every three (3) years to maintain that population. The report also recommended that a creel survey be conducted to measure angler interest in, and the harvest rate of, the stocked saugeye and channel catfish.

The 1988 fish management report documented the results of the previously recommended creel survey, conducted from 1 April - 31 October 1988. The creel survey showed fishing pressure to be highest in May (21,916 fishing hours), then declining throughout the summer. Fishing pressure was lowest in August and October (6807 and 6848 fishing hours, respectively). The survey found that Sullivan Lake anglers fish primarily for crappie, largemouth bass and bluegill, although saugeye and channel catfish were the fourth and fifth most abundant fish harvested. The majority of the anglers interviewed were aware of the saugeye and channel catfish stocking programs, although only a small percentage of the anglers were specifically interested in saugeye. The fishery report recommended that both stocking programs be continued. Although interest in the saugeye was low, the harvest rate suggested that saugeye were a desirable addition to the fishery, and that interest in the fishery could be expected to grow.

2.3 RECREATIONAL USE OF SULLIVAN COUNTY PARK AND LAKE

Information obtained from the Sullivan County Park and Recreation District for the period 1969 - 1989 shows the annual Park income to have increased substantially (631%) over the past 20 years. It is probable that the Park District has realized a roughly parallel increase in recreational use for this same time period. Documentation of the number of entrance passes sold, on an annual as well as daily basis, and the number of cars, buses and walk-ins entering the Park for 1987 through 1989 indicates an overall increase of five (5) percent in Park use for that time period. Park use in 1988, based on the total entrance fees collected, was 22 percent higher than 1987. In 1989 Park use declined slightly, but it has been estimated that at least 100,000 persons used Sullivan County Park that year (Sullivan County Park and Recreation District., pers. comm.).

A comparison of the number of boat launch permits issued on an annual basis from 1987 through 1989 shows that, in each year, at least four (4) times as many permits were sold to power boats (engines 7.5 HP and up) as were sold to fishing boats (engines less than 7.5 HP). Additionally, the number of power boat annual launch permits increased from 133 in 1987 to 170 in 1989 (28%). The number of fishing boat annual launch permits increased from 33 in 1987 to 39 in 1988, then decreased to 37 in 1989. The net increase in fishing boat annual permits for 1987 through 1989 was 12%, or slightly less than half of the increase for power boats.

Information pertaining to the number of boats paying daily launch fees, as opposed to purchasing an annual launch permit, is not available for 1987 and 1988. During the 1989 season, however, there were 12 times as many power boats launched, on a daily basis, as fishing boats. The daily power boat launches in 1989 totaled 4,146, while the fishing boat launches totaled only 349.

2.4 LAND USE

Data obtained from the Conservation Technology Information Center (CTIC) for 1984 and 1988 showed the majority of the cropland in Sullivan County to be used for corn production, followed by soybeans and small grain crops such as wheat, barley, rye and oats. In 1984, conservation tillage was practiced on 38 percent of the active cropland. The primary type of conservation tillage practiced was mulch-till, where the total soil surface is disturbed just prior to planting, and weed control is accomplished using a combination of herbicides and cultivation. Mulch-till conservation tillage was used on 22.5 percent, and no-till conservation tillage was practiced on 10 percent of the cropland in 1984. In 1988, the number of acres used for crop production declined to 77 percent of the 1984 active cropland acreage. Conservation tillage was practiced on 39 percent of that land. Mulch-till was still the primary type of conservation tillage practiced, and was used on 31 percent of the cropland. No-till conservation tillage was practiced on 7 percent of the active cropland. The 1988 data also indicates 642 acres of cropland dedicated to the Conservation Reserve Program as well as 14,749 acres of highly erodible land identified in Sullivan County (CTIC, 1989).

2.5 SIGNIFICANT NATURAL AREAS AND ENDANGERED/IMPORTANT SPECIES

There were no significant natural areas and endangered and threatened species identified in the Sullivan Lake watershed by the IDNR Division of Nature Preserves. The Division of Nature Preserves has a database of information pertaining to these significant areas and species, and can identify their locations by USGS quadrangle map, giving latitude and longitude coordinates. Table 5 contains a listing of species that the Division of Nature Preserves considers as "possible elements" that may be found in the watershed.

Table 5. Significant natural areas and endangered/threatened species in the Sullivan Lake watershed.

USGS QUADRANGLE	NATURAL AREA	SPECIES COMMON NAME	SPECIES SCIENTIFIC NAME	STATUS	LAT.	LONG.
Dugger	no significant natural areas or endangered/threatened species					
Hymera	no significant natural areas or endangered/threatened species					
Shelburn	no significant natural areas or endangered/threatened species					
Sullivan	no significant natural areas or endangered/threatened species					

Possible endangered/threatened species in this watershed:

		Loggerhead Shrike	Lanius ludovicianus		SE
		Yellow-Crowned Night Heron	Nyctanassa violaceus		SE
		Eastern Massasauga	Sistrurus catenatus	ST	
		Badger	Taxidea taxus		ST

Status: SE = endangered; ST = threatened; SR = rare; SCC = special concern; WL = watch list; # = observed prior to 1960

SECTION 3. METHODS

This section of the report describes the methods used to complete the Sullivan Lake feasibility study. The data collection efforts for this project were divided into two sub-tasks: (1) a reservoir survey, and (2) a watershed survey. These subtasks are described below.

3.1 RESERVOIR SURVEY

IS&T personnel conducted a survey of Sullivan Lake during the late summer and fall of 1989 to collect the information required for a detailed assessment of the physical, chemical and biological conditions in the reservoir, as well as the condition of the shoreline. Samples were collected to analyze reservoir water quality, phytoplankton species and abundance, and sediment composition. The location and composition of emergent, floating and submergent vegetation was determined. A survey of near shore bathymetry and shoreline erosion were conducted to quantify the extent of bank erosion and the suitability of alternative erosion measures. The methods used for sample collection and other components of the field survey are described below.

3.1.1 In-situ Measurements

In-situ water quality, water samples and phytoplankton were collected on 28 August 1989 at one (1)in-lake station located at the deepest part of the reservoir (Figure 4). In-situ profile measurements of temperature, dissolved oxygen and Ph were made using a Hydrolab "Surveyor II" Environmental Data System. Measurements were recorded at two (2) foot intervals from the water surface to immediately above the sediment surface. Secchi disk transparency was measured on the shaded side of the boat. The Secchi disk was lowered until it disappeared, and then raised until it reappeared. The average of these two depths was reported as the Secchi disk depth. Percent light transmission was recorded at three feet using a Martek Model XMS transmissometer. This instrument was calibrated on the boat prior to use.

3.1.2 Chemical Measurements

Water samples were collected from the water column of Sullivan Lake on 18 August, and again on 28 August 1989. Equipment problems on the first sampling date necessitated a return trip on 28 August. On both sampling dates, three (3) water samples were collected from the surface, mid-depth (9 feet) and approximately one (1) foot above the reservoir bottom (18 feet) using a 6-L (6.6 quart) vertical Van Dorn water sampler. All in-lake water samples were collected at the same location as the in-situ data. The sample from each depth was poured directly from the Van Dorn into a clean 4-L Cubitainer container. All samples were immediately placed in coolers and stored at 4 C prior to shipment to the IS&T analytical laboratory. The samples were received at the laboratory and the analyses begun within 24 hours of collection. Table 6 lists the analytes measured in the water samples and the methods used to conduct the

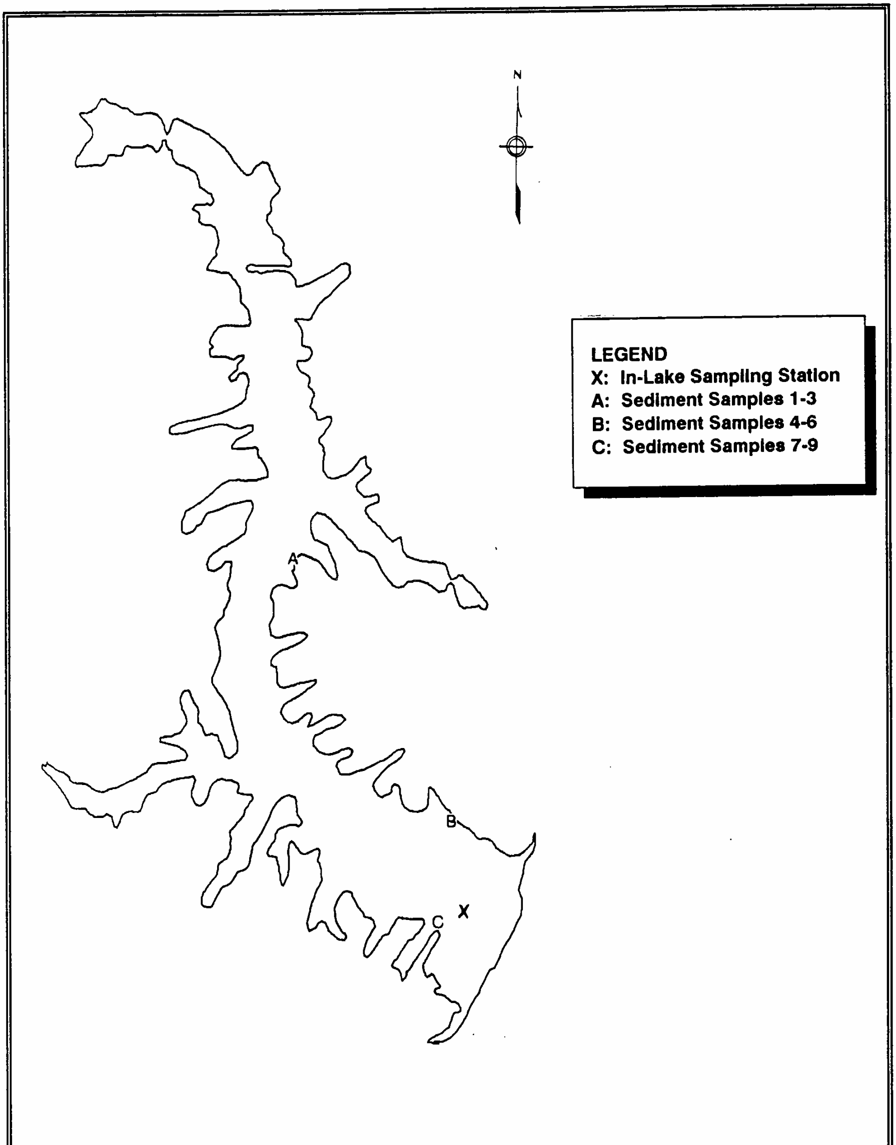

Figure 4. In-lake and sediment sampling locations.

Table 6. Chemical parameters and analytical methods used in evaluating Sullivan Lake water samples.

PARAMETER	INSTRUMENT OR METHOD	REFERENCE
Chlorophyll a (Chla)	Spectrophotometer	Standard Methods, 16th ed.
Ammonia ($N-NH_4$)	Flow Injection Analysis	EPA 350.1
Nitrate (NO_3)	Flow Injection Analysis	EPA 383.2
Total Kjeldahl Nitrogen (TKN)	Flow Injection Analysis	EPA 351.2
Ortho Phosphorus (OP)	Flow Injection Analysis	EPA 365.1
Total Phosphorus (TP)	Flow Injection Analysis	EPA 365.1
Total Suspended Solids (TSS)	Gravimetric	EPA 160.2
Temperature	In-situ Hydrolab Surveyor II	
Dissolved Oxygen (DO)	In-situ Hydrolab Surveyor II	
Ph	In-situ Hydrolab Surveyor II	

analyses.

In addition to the water samples, quality assurance samples were also collected in the field and included in the shipment to the analytical laboratory. These samples consisted of a blank (deionized water that was poured into the Van Dorn and then into a Cubitainer) and a duplicate sample. The blank sample was used to evaluate potential contamination due to field procedures. The duplicate sample, obtained from a second water sample collection at one of the three (3) depths, provided a measure of variability within the analytical system.

3.1.3 Biological Sample Collection

Phytoplankton were collected from Sullivan Lake on 18 August and on 28 August. On each date, vertical plankton tows were taken using an 80μ mesh plankton net with an opening of one (1) foot. The tows were taken from the same in-lake sampling station as the in-situ and chemical measurements. On 18 August, one plankton tow was taken from a depth of five (5) feet to the surface. On 28 August, the first plankton tow was again taken from a depth of five (5) feet to the surface. The second was from a depth of 14 feet and included the thermocline. The plankton samples were immediately preserved with Lugol's solution and stored in labeled, opaque bottles. Phytoplankton were identified to species and enumerated using the settling chamber-inverted microscope technique described by H. Utermöhl (Sournia, 1972).

3.1.4 Sediment Sample Collection

A sediment survey was conducted in Sullivan Lake in three (3) areas of excessive shoaling (Figure 4). Three sediment samples were collected per shoal area. The hard bottom in these areas prevented the effective use of a sediment corer, therefore a sediment scoop was utilized to obtain the samples. The top three (3) inches of sediment from each sample were placed in 250 ml containers and shipped in coolers to the laboratory. Particle size analyses were conducted on each sample to assess the likelihood of sediment resuspension.

3.1.5 Aquatic Vegetation

An aquatic plant survey of Sullivan Lake was conducted to quantify the distribution of submerged, emergent and floating macrophytes. Plants were identified to the species level in the field. Areal coverage was sketched on a map of the lake, and later digitized into IBM-PC compatible data files. Separate maps were prepared for the floating, emergent, and submergent species identified. A Manual of Aquatic Plants (Fassett, 1980) was used for identification.

3.1.6 Bathymetric Survey

A bathymetric survey of the entire reservoir was conducted using a recording fathometer (Lowrance "Eagle"). Survey transects ran perpendicular to the lake shore, and were created by triangulating from unique shoreline features. The latter provided reference points that allowed accurate placement of survey transects on USGS topographic maps. Care was taken to maintain constant boat speed during each transect run. Soundings from this survey were then plotted on a map of the reservoir, the same map that depicts shoreline erosion (see below).

3.1.7 Shoreline Survey

A site reconnaissance of the entire reservoir shoreline and tributaries was conducted. All areas of existing erosion and bank instability were documented on a reservoir map. This map, prepared at a scale of 1 to 400, shows four classes of erosion severity, and the number of linear feet in each category. The shoreline survey provided the detail necessary to specify restoration strategies for the Sullivan Lake shoreline.

3.2 WATERSHED SURVEY

Characterization of the current conditions in the Sullivan Lake watershed was oriented toward identifying the principal sources of sediment and nutrient loading. Components of this survey included:

- Hydrologic characterization
- Land use delineation
- Sediment/nutrient modeling.

3.2.1 Hydrological Data

The principal hydrologic parameter of interest in developing a restoration strategy for Sullivan Lake is the hydraulic retention time. This is defined as the length of time required for the entire volume of the lake to be replaced with "new" water from runoff and direct precipitation. The information used in calculating the residence time included the lake volume, average annual runoff for the Sullivan Lake watershed, annual rainfall, and evaporation from the surface of the lake.

3.2.2 Land Use Delineation

Major land use patterns in the Sullivan Lake watershed were identified using recent (1987) aerial photographs (1:2000 scale) of the lake and watershed, USGS topographic maps (1:24,000 scale), and site reconnaissance. Several steps were necessary to develop the final land use map of the entire watershed.

First, the watershed boundary was outlined on topographic maps and digitized into IBM-PC compatible data files along with key geographical features (e.g., lake shorelines, streams, roads and towns). Land use within the watershed was delineated using aerial photographs, and assigned to one of sixteen (16) unique land use categories. The land use types used are shown in Table 7. The border of each land use type was then digitized into IBM-PC compatible data files. These files were overlain onto the watershed boundary and geographical feature data files. Coverage maps and tabular summaries of land use in the watershed, as well as the data files to produce them, were developed using IS&T proprietary software. The results of this task were used as input parameters for modeling sediment and nutrient loading to the watershed (Section 3.2.3).

Table 7. Land use categories designated in the watershed survey.

1. Water Surface
2. Wetlands (including approximate stream corridors)
3. Forest (tree groups larger than 0.25 acre)
4. Open Land/Vacant Lots (no structures or livestock)
5. Pasture (grazed lands)
6. Row Crops (corn, beans, etc.)
7. Non-row Crops (wheat, hay, etc.)
8. Orchard
9. Feedlot
10. Low Density Residential/Rural (1 dwelling/acre)
11. Medium Density Residential (2-5 dwellings/acre)
12. High Density Residential (6 or more dwellings/acre)
13. Commercial/Industrial (industrial parks, malls)
14. Institutional (schools, parks, golf courses)
15. Bare/Unseeded Ground (construction sites)
16. Resource Extraction (borrow pits, timber sites)

3.2.3 Sediment/Nutrient Modeling

Information on land use, climate, soils and hydrology were combined to provide input parameters for use in the Agricultural Non-Point Source Pollution Model (AGNPS), a system developed by the U.S. Department of Agriculture-Agricultural Research Service in cooperation with the Minnesota Pollution Control Agency and the Soil Conservation Service. The PC-based model was designed to simulate the sediment and nutrient contributions from watersheds under predefined hydrologic conditions. AGNPS operates on a grid basis and requires that the watershed be divided into a series of discrete squares, or cells. Twenty-two input parameters, covering a wide range of physical and chemical characteristics are assigned to each cell (Table 8). Sediment and nutrients are routed through the watershed; their concentrations in each cell being a function of upstream loading and the unique cell attributes, which can either increase or diminish the non-point pollution load. Sediment, nutrient, and hydrologic characteristics may be summarized for any cell along the flow path and at the watershed outlet. The model also allows the user to highlight cells with specific characteristics, such as high sediment phosphorus. In addition, land use and other characteristics may be hypothetically altered to determine the effect of future changes on sediment and nutrient loading. The model provides estimates for single precipitation events only, so the user must define a "design storm" for the analysis.

Based on recommendations of AGNPS developers, the Sullivan Lake watershed was divided into a series of 40-acre cells. Each cell was characterized according to the parameters listed in Table 8. The design storm chosen was a two year, 24-hour event. This is defined as the largest storm that can be expected to occur once every two years, based on a 30 year period of record. For Sullivan Lake, this was a 3.1

Table 8. Input parameters used in the AGNPS model[1].

TITLE	DESCRIPTION
Cell Number	ID number of current cell
Receiving Cell	ID of cell receiving outflow from current cell
SCS Curve Number	Relates runoff mass to rainfall mass (inches)
Field Slope	Mean slope of fields (%)
Slope Shape	Indicates concave, convex or uniform slope shape
Slope Length	Indicates average field slope length (feet)
Channel Slope	Mean slope of stream channel (%)
Side Slope	Mean slope of stream channel banks (%)
Roughness	Manning's Roughness Coefficient for channels
Soil Erodibility	K-Factor from Universal Soil Loss Equation
Crop Practice	C-Factor from Universal Soil Loss Equation
Conservation Practice	P-Factor from Universal Soil Loss Equation
Surface Condition	Indicates degree of land surface disruption
Aspect	Principal drainage direction
Soil Texture	Indicates sand, silt, clay or peat
Fertilization	Indicates level of added fertilizer
Incorporation	Indicates % fertilizer left on soil after storm
Point Source Flag	Indicates presence/magnitude of any point source
Gully Source	Override estimate of gully erosion magnitude
COD	Level of chemical oxygen demand generated
Impoundment Flag	Indicates presence/absence of terrace systems
Channel Flag	Indicates presence/absence of defined streams

[1] Parameters represent estimated conditions within each cell.

inch rainfall (U.S. Department of Commerce, 1966). Nutrient, sediment and runoff maps were produced using the AGNPS Graphical Interface System.

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SECTION 4. RESULTS AND DISCUSSION

4.1 RESERVOIR SURVEY

This investigation included in-situ, chemical and biological water quality measurements; sediment analyses; aquatic macrophyte distribution mapping; and bathymetric mapping. These data were used to summarize late summer conditions in the reservoir and assess its current trophic status.

4.1.1 In-situ Measurements

In-situ water quality measurements are presented in Table 9 and Figures 5a, 5b and 5c. These data indicate that Sullivan Lake exhibited a weak thermal stratification at the time of sampling. The

Table 9. Sullivan Lake in-situ water quality measurements. (28 August 1989)

DEPTH (ft)	TEMP (C)	DO (mg/L)	pH	% TRANS. @3FT	SECCHI DISK (ft)
0.0	27.40	9.53	8.47	11.10	2.05
2.0	27.41	9.46	8.37		
4.0	27.40	9.43	8.35		
6.0	27.34	9.16	8.29		
8.0	26.61	5.28	7.62		
10.0	26.12	2.32	7.19		
12.0	25.76	0.12	6.99		
14.0	24.95	0.09	6.99		
16.0	23.89	0.07	7.02		
18.0	22.42	0.05	7.06		
20.0	21.57	0.05	7.07		

temperature difference between the surface and lake bottom was 5.8 C.

Dissolved Oxygen (DO) concentrations in Sullivan Lake were between 9.5 and 9.2 mg/L from the surface to a depth of 6 feet. All four readings, from the surface through six (6) feet, were supersaturated. The oxygen concentration dropped sharply between the eight (8) and 10 foot depth measurements, with anoxic conditions from 10 feet to the lake bottom. The clinograde DO profile (Figure 5b) is characteristic of temperate lakes in mid to late summer, and is generally indicative of productive, often eutrophic conditions.

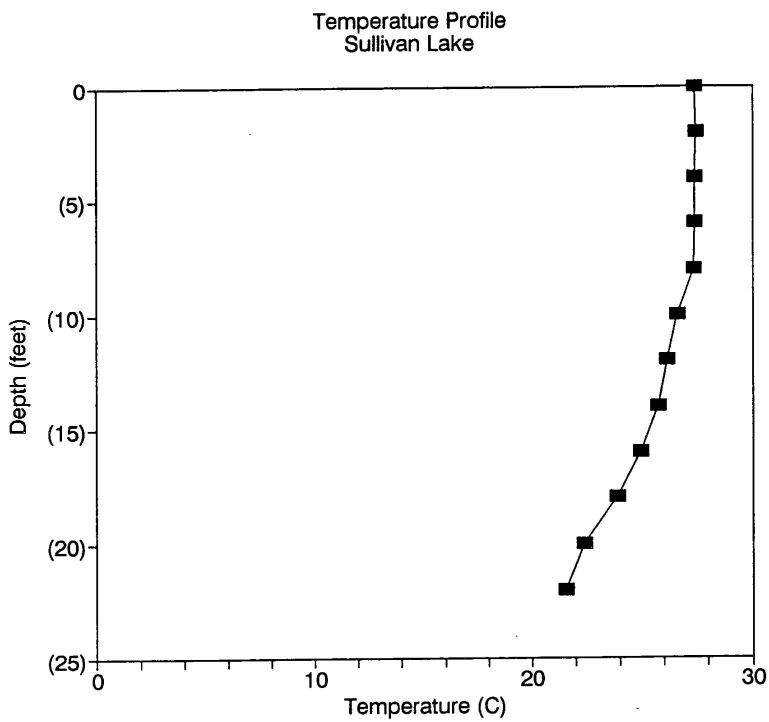

Figure 5a. Sullivan Lake temperature profile (28 August 1989).

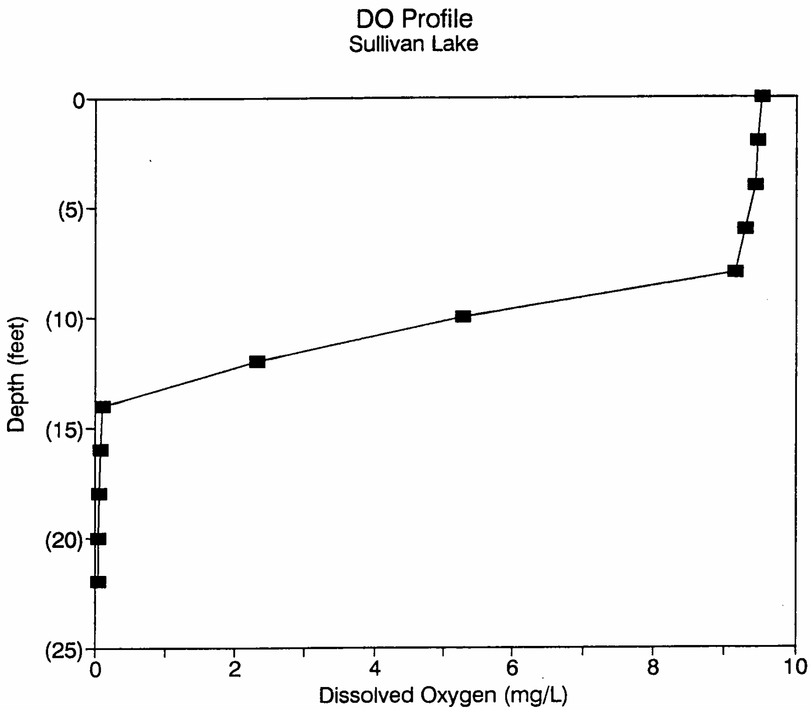

Figure 5b. Sullivan Lake dissolved oxygen profile (28 August 1989).

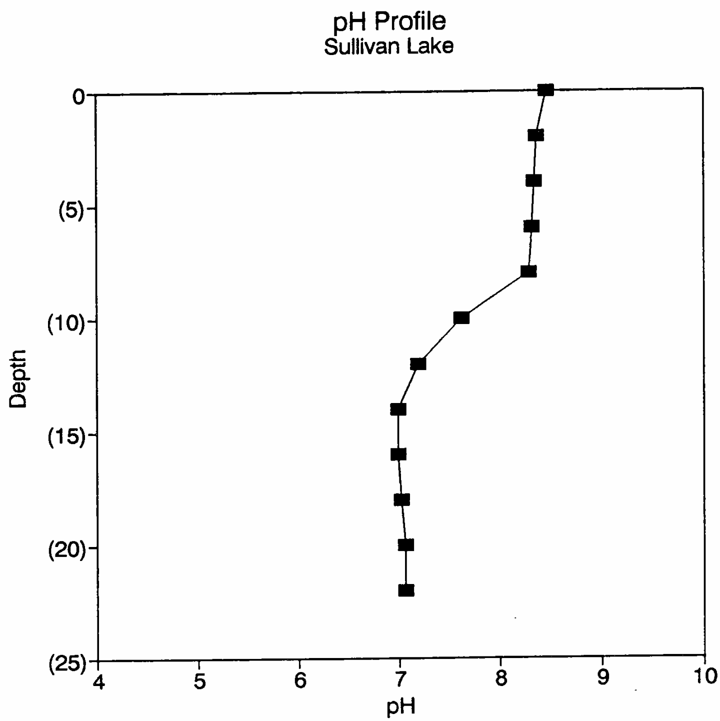

Figure 5c. Sullivan Lake pH profile (28 August 1989).

The pH distribution in the water column was typical of a productive reservoir. Values in the top six (6) feet of the water column were higher than those below, ranging from 8.5 to 8.3. The higher pH values in the upper six (6) feet of the water column are a result of photosynthetic utilization of carbon dioxide (CO_2), a weak acid. As CO_2 is utilized and its concentration in the water column is reduced, pH increases.

4.1.2 Chemical Measurements

The results of water quality analyses for in-lake samples collected on 18 August and again on 28 August are shown in Tables 10 and 11, respectively. The analytical results for the samples collected on 18 August are indicative of eutrophic conditions. Higher concentrations of TP, TKN, NO3, and N-NH4 were found in the bottom sample than in the mid-depth or surface samples. These data reflect nutrient release from the sediments under anoxic conditions.

The analytical results for the water samples collected on 28 August (Table 11) were also indicative of eutrophic conditions, with the bottom sample having higher concentrations of TP, TKN, and N-NH4 than the mid-depth or surface samples. The NO3 concentration showed little variation between the mid-depth and bottom samples, although both samples had higher concentrations than the surface sample, which was below detection. The total suspended solids (TSS) concentration in Sullivan Lake ranged from 5.80 mg/L to 7.25 mg/L. The highest concentration of TSS was found in the bottom sample, with the second highest concentration at the surface.

The ratio of total nitrogen to total phosphorus (N:P) is often used to evaluate the relative importance of these two algal nutrients, which are quickly taken up in their soluble forms (i.e., ortho-phosphorus and nitrate). Algae are characteristically luxury consumers of phosphorus, taking up available phosphorus in excess of immediate physiological requirements. Thus, the concentrations of the soluble forms are not necessarily indicative of available supply (Welch, 1980). However, the ratio of the total concentrations can be used to assess which nutrient will be limiting to plant growth (i.e., the first to be used completely following continued growth) under optimal physical conditions where light and temperature are not inhibiting.

Nitrogen is rarely limiting in freshwater systems due to its abundance in the atmosphere and availability through nitrogen fixation by blue-green algae. Phosphorus is generally the limiting nutrient in these systems. However, in eutrophic lakes where phosphorus is extremely abundant, nitrogen may be limiting. As a general rule, if the N:P ratio is 17 or greater, phosphorus is most likely the limiting nutrient. N:P ratios less than 13 are usually indicative of nitrogen limitation (Cooke, et. al., 1986). Either nitrogen or phosphorus may be limiting when ratios are between 13 and 17.

The N:P ratios of the surface (14.8) and mid-depth (13.4) samples collected 18 August indicate neither phosphorus nor nitrogen limitation. The low N:P ratio of the bottom sample (6.6) would suggest nitrogen

Table 10. Sullivan Lake water quality results for in-lake samples.

SAMPLE ID	SAMPLE DEPTH (ft)	DATE COLLECTED	TIME COLLECTED	CHL A (mg/m3)	COND @ 25C (uS)	N-NH4 (mg/L)	NO3 (mg/L)	TKN (mg/L)	OP (mg/L)	TP (mg/L)
S-SURF	0.0	08/18/89	14:30	42.5	215.0	0.07	0.018	0.753	0.042	0.052
S-MID	9.0	08/18/89	14:45	28.8	217.0	< 0.05	0.019	0.517	0.031	0.040
S-BOTTOM	18.0	08/18/89	15:00	10.5	305.0	2.15	0.041	2.780	0.035	0.426

CHL A = Chlorophyll a; COND = Conductivity @ 25 C; N-NH4 = Ammonia; NO3 = Nitrate;
TKN = Total Kjeldahl Nitrogen; OP = Ortho Phosphorus; TP = Total Phosphorus

Table 11. Sullivan Lake water quality results for in-lake samples.

SAMPLE ID	SAMPLE DEPTH (ft)	DATE COLLECTED	TIME COLLECTED	CHL A (mg/m3)	N-NH4 (mg/L)	NO3 (mg/L)	TKN (mg/L)	OP (mg/L)	TP (mg/L)	TSS (mg/L)
S-SURF	0.0	08/28/89	9:55	42.6	0.02	< 0.083	2.006	< 0.005	0.077	6.50
S-MID	9.0	08/28/89	10:00	36.3	0.07	0.097	1.645	< 0.005	0.062	5.80
S-BOTTOM	18.0	08/28/89	10:08	13.2	1.14	0.099	3.027	0.039	0.136	7.25

CHL A = Chlorophyll a; N-NH4 = Ammonia; NO3 = Nitrate; TKN = Total Kjeldahl Nitrogen;
OP = Ortho Phosphorus; TP = Total Phosphorus; TSS = Total Suspended Solids

limitation, but is clearly the result of a high phosphorus concentration at that depth. N:P ratios of the samples collected 28 August, however, were all greater than 23 and clearly indicative of a phosphorus limited system.

A comparison of the phosphorus and nitrogen analytical results for both sampling dates reveals an increased concentration of TP at the surface and mid-depth, and a decrease in TP in the bottom sample on 28 August. TKN and NO_3 concentrations increased at all three depths on 28 August. Additionally, OP concentrations in the surface and mid-depth samples had decreased to below analytical detection limits, indicating the available forms of phosphorus had been consumed by the algal population. The weak thermal stratification present in the reservoir on 28 August (Figure 5a) indicates the possibility of destratification and increased mixing, allowing the TP in the bottom waters to diffuse into the overlying strata. This would serve to decrease the TP concentration in the bottom samples, and increase it in the surface and mid-depth samples.

4.1.3 Biological Measurements

The results of the Chla analyses indicate the greatest amount of photosynthesis, on both sampling dates, occurred between the surface and 9 ft. The pigment concentration observed in the surface (42.5 mg/m^3, and 42.6 mg/m^3) and mid-depth (28.8 mg/m^3, and 36.3 mg/m^3) samples on both sampling dates suggests highly productive waters. On both dates, Chla values dropped sharply in the bottom samples as light and temperature levels became limiting to phytoplankton.

The results of the phytoplankton identification and enumeration for the Sullivan Lake sample collected 18 August 1989 showed an algal community of 17 species representing 4 classes (Table 12). The algal community was dominated by the blue-green algae, which comprised 72.5 percent of the 5 foot tow (Figure 6). Numerically, the dominant specie was the blue-green algae Aphanocapsa delicatissima. Important algal species included Aphanothece gelatinosa, a blue-green algae and Pediastrum simplex v duodenarium, a green algae.

Identification and enumeration of the phytoplankton samples collected on 28 August 1989 showed an algal community comprised of 32 species representing 5 classes (Table 13). Again, the algal community was dominated by the blue-green algae, comprising approximately 45 percent of the 5 foot tow, and 51.4 percent of the 14 foot tow (Figures 7a and 7b). A diatom, Fragilaria crotonensis was the dominant algal specie, with numerically important blue-green algal species including Lyngbya birgei and Oscillatoria limnetica. Blue-green algal dominance is another indication of eutrophic conditions in the lake and substantiates the conclusion that phosphorus is the limiting nutrient.

Table 12. Sullivan Lake phytoplankton identification and cell count/ml. (18 August 1989)

	CELLS PER SAMPLE 5 FT. TOW
Sample Volume Total (ml)	142.0
Volume of Sample Settled for ident. (ml)	3.0
SPECIES	
Chlorophyta (green algae)	
Chlamydomonas sp	*
Pandorina morum	*
Pediastrum simplex	157,000
Pediastrum simplex v duodenarium	429,000
Sphaerocystis Schroeteri	*
Tetraedron minimum	28,600
Tetraedron gracile	14,300
Total Chlorophyta cells per sample	628,900
Total Chlorophyta cells per ml settled	4,429
Chrysophyta (diatoms, chrysophytes, etc.)	
Cyclotella sp 25u	157,000
Cyclotella sp 15u	42,900
Melosira granulata	257,000
Stephanodiscus sp 18u	14,300
Synedra acus	42,900
Synedra sp	14,300
centric diatoms < 10u	42,900
Total Chrysophyta cells per sample	571,300
Total Chrysophyta cells per ml settled	4,023
Pyrrophyta (yellow-browns)	
Katodinium rotundatum	*
Total Pyrrophyta cells per sample	0
Total Pyrrophyta cells per ml settled	0
Cyanophyta (blue-green algae)	
Aphanocapsa delicatissima	1,590,000
Aphanothece gelatinosa	1,460,000
Merismopedia punctata	57,200
blue-green filaments	57,200
Total Cyanophyta cells per sample	3,164,400
Total Cyanophyta cells per ml settled	22,284
Total phytoplankton cells per sample	4,364,600
Total phytoplankton cells per ml settled	30,736

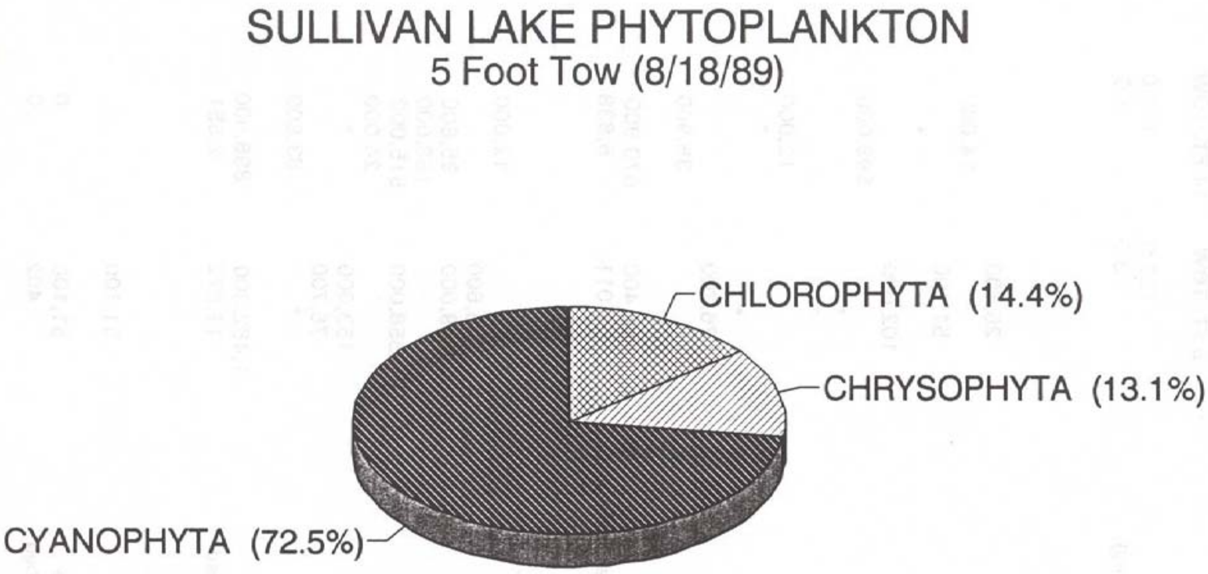

Figure 6. Phytoplankton composition from five foot tow, 18 August, 1989.

Table 13. Sullivan Lake phytoplankton identification and cell count/ml. (28 August 1989)

	CELLS PER SAMPLE 5 FT. TOW	14 FT. TOW
Sample Volume Total (ml)	127.0	119.0
Volume of Sample settled for ident. (ml)	3.0	3.0
SPECIES		
Chlorophyta (green algae)		
Ankistrodesmus falcatus	25,600	
Ankistrodesmus convolutus		24,000
Chlamydomonas sp	51,100	
Fragilaria crotonensis		*
Gloeocystis gigas	102,000	
Pediastrum simplex v duodenarium		599,000
Schroederia setigera	*	
Selenastrum sp	*	
Tetraedron minimum		12,000
Tetraedron regulare		*
Tetrastrum heteraeanthum	*	
Treubaria setigerum	76,700	
green flagellates		35,900
Total Chlorophyta cells per sample	255,400	670,900
Total Chlorophyta cells per ml settled	2,011	5,638
Chrysophyta (diatoms, chrysophytes, etc.)		
Cyclotella sp		12,000
Dinobryon sp	25,600	
Fragilaria crotonensis	869,000	95,800
Melosira granulata		168,000
Melosira sp	358,000	515,000
Synedra acus		24,000
centric diatoms < 10u	153,000	*
pennate diatoms < 25u	76,700	
pennate diatoms > 25u	*	83,800
Total Chrysophyta cells per sample	1,482,300	898,600
Total Chrysophyta cells per ml settled	11,672	7,551
Euglenophyta (euglenoids)		
Euglena sp	51,100	
Total Euglenophyta cells per sample	51,100	0
Total Euglenophyta cells per ml settled	402	0

Table 13. Sullivan Lake phytoplankton identification and cell count/ml.
(28 August 1989 - concluded)

	CELLS PER SAMPLE	
	5 FT. TOW	14 FT. TOW
Sample Volume Total (ml)	127.0	119.0
Volume of Sample settled for ident. (ml)	3.0	3.0
SPECIES		
Pyrrophyta (yellow-browns)		
Ceratium hirudinella	25,600	
Cryptomonas erosa	51,100	
Cryptomonas ovata	25,600	
Cryptomonas pusilla	51,100	
Total Pyrrophyta cells per sample	153,400	0
Total Pyrrophyta cells per ml settled	1,208	0
Cyanophyta (blue-greens)		
Aphanothece gelatinosa		347,000
Chroococus dispersus		216,000
Gomphosphaeria lacustris	*	
Lyngbya Birgei	844,000	*
Merismopedia minima	*	
Merismopedia punctata		47,900
Merismopedia tenuissima	*	*
Microcystis aeruginosa		718,000
Oscillatoria limnetica	588,000	204,000
blue-green monads		144,000
blue-green filaments	153,000	
Total Cyanophyta cells per sample	1,585,000	1,676,900
Total Cyanophyta cells per ml settled	12,481	14,092
Total phytoplankton cells per sample	3,527,200	3,246,400
Total phytoplankton cells per ml settled	27, 774	27,281

* Species was found during scans of the subsample but not seen during the actual count.

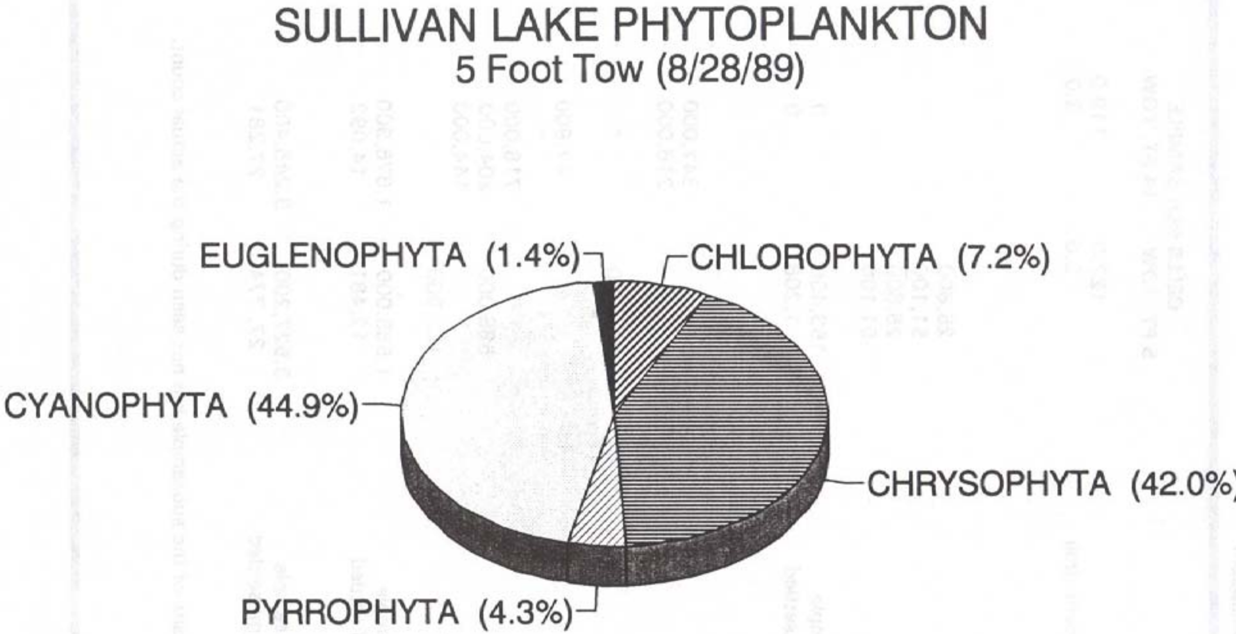

Figure 7a. Phytoplankton composition from five foot tow, 28 August, 1989.

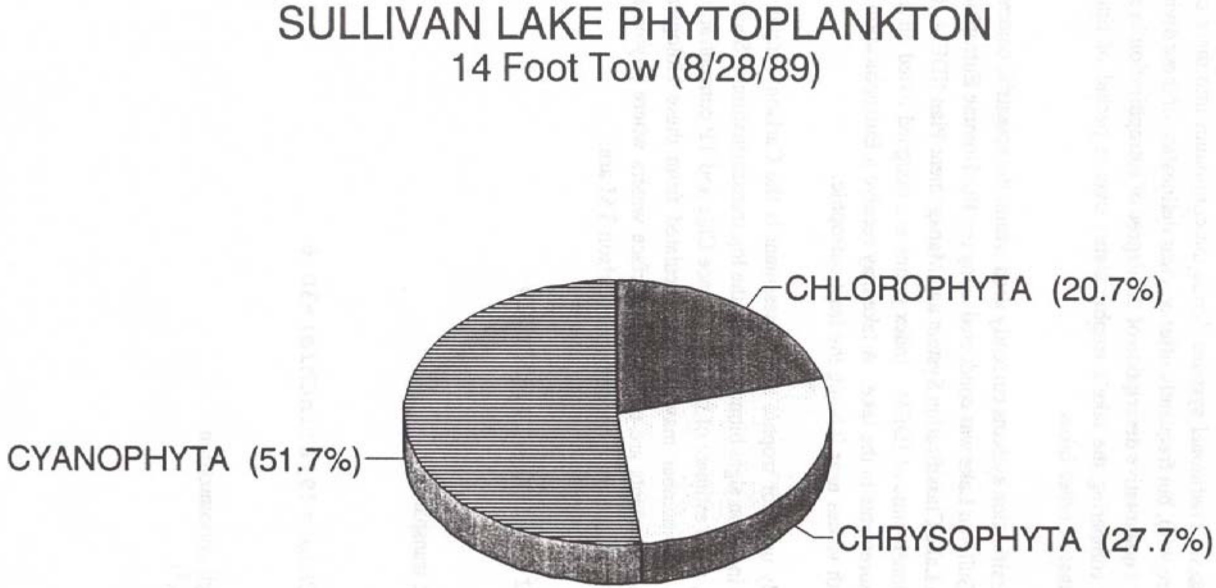

Figure 7b. Phytoplankton composition from 14 foot tow, 28 August, 1989.

4.1.4 Trophic State Assessment

The biological, chemical and physical characteristics of a lake can be incorporated into an index number to describe its trophic state. Historically, trophic classifications have been based on the division of the trophic continuum into a series of classes. Traditional systems divide the continuum into three classes (i.e., oligotrophic, mesotrophic and eutrophic), but frequently offer no clear delineation of these divisions. Calculating a trophic state index allows a quantitative description of the degree of eutrophication in a lake, and provides a basis for numerically comparing the lake's trophic status over a period of time and forcomparing its trophic state against that of other lakes.

There are several numerical trophic classification systems currently used within the scientific community. A previous trophic state assessment of Sullivan Lake was conducted using the BonHomme Eutrophication Index and is documented in the Indiana Lake Classification System and Management Plan (IDEM, 1986). The index was developed by Harold BonHomme of IDEM. Index points are assigned based on diverse chemical, physical and biological measurements in the lake. A lake may receive a Eutrophication Index (EI) number ranging from 0 to 75, with values near 0 being the least eutrophic.

Another numerical index that is widely used for trophic state assessment is the Carlson Trophic State Index (TSI). Carlson (1977) based his index on algal biomass using the log transformation of Secchi disk transparency, a physical measurement, as an estimate of biomass. Since Chla and TP concentrations are often correlated with transparency, a TSI number may also be calculated from these biological and chemical measurements. All three measurements are taken from surface waters where phytoplankton productivity is at its peak. The equations used for computing the Carlson TSI are:

$$TSI(SD) = 60 - (14.41 \ln SD)$$

Where:
TSI(SD) = TSI based on Secchi disk transparency
SD = Secchi transparency (m)

$$TSI(Chla) = (9.81 \ln Chla) + 30.6$$

Where:
TSI(Chla) = TSI based on chlorophyll concentration
Chla = Chlorophyll a (mg/m^3)

$$TSI(TP) = (14.42\ln TP) + 4.15$$

Where:
TSI(TP) = TSI based on total phosphorus concentration
TP = Total phosphorus (mg/m^3)

The Carlson TSI classifies lakes on a scale of 0 to 100, with each major scale division (i.e., 10, 20, 30, ...) representing a doubling in algal biomass. Under ideal circumstances, the three separate TSI values should be similar. Under realistic conditions, however, the index values will exhibit some variability. It is this variability that reveals the basic differences in the ecological functioning of the aquatic system. The accuracy of Carlson's TSI based on Secchi disk measurement alone is diminished by the presence of non-algal particulate matter or highly colored water. The index number derived from the Chla values, when available, is best for estimating algal biomass, and priority should be given for its use as a trophic state indicator (Carlson, 1977).

A BonHomme Eutrophication Index (EI) number was calculated for Sullivan Lake using the water quality data collected during the 28 August 1989 field survey. The number of EI points assigned was based on a newly revised EI scale as developed by IDEM. This revision now bases points assigned to phytoplankton results on the number of organisms per liter of water samples. The EI scale with respect to phytoplankton has also been adjusted. Table 14 presents the details of the EI calculation. There is one source of uncertainty in this EI calculation that should be noted. The phytoplankton sample from the thermocline was collected in a manner inconsistent with the technique used by BonHomme. A closed sample from the thermocline only, rather than a vertical tow from the thermocline to the surface, is the method used on lakes previously sampled by IDEM. Based on the recommendations of Mr. BonHomme (pers. comm.), the data collected from the 5 foot tow was used to estimate the phytoplankton count in the thermocline.

Previously, the IDEM calculated an EI number of 39 for Sullivan Lake. More recent data, collected in 1988 for the IDEM, resulted in the calculation of an EI number of 46 (BonHomme, pers. comm.). The EI number based on data collected 28 August 1989 was 36, placing the lake in the Class Two trophic category as previously described in Section 1.2. This is the same Class that the lake was assigned to based on the earlier measurements. A comparison of the data used to calculate the previous EI number of 39 with the current data is not possible, as the previous data is not available (BonHomme, pers. comm.). However, a comparison of the 1988 water chemistry data with the data collected in 1989 by IS&T shows a decrease in TP and $N\text{-}NH_4$ concentrations. The remaining parameters showed no significant increases or decreases between the two years.

Calculation of the Carlson TSI was based on the Chla and TP concentrations in the surface waters, as well as the Secchi disk transparency of Sullivan Lake. Table 15 presents the results of these calculations. The

Table 14. BonHomme Eutrophication Index Calculations for Sullivan Lake (28 August 1989).

Parameter and Range	Range Value	Range Observed	Point Value
Total Phosphorus (mg/L)			
Observed Mean: 0.09			
At least 0.03	1		0
0.04 to 0.05	2		0
0.06 to 0.19	3	X	3
0.20 to 0.99	4		0
0.99 or more	5		0
Soluble Phosphorus (mg/L)			
Observed Mean: 0.01			
At least 0.03	1		0
0.04 to 0.05	2		0
0.06 to 0.19	3		0
0.20 to 0.99	4		0
1.00 or more	5		0
Organic Nitrogen (mg/L)			
Observed Mean: 1.82			
At least 0.05	1		0
0.60 to 0.80	2		0
0.90 to 1.90	3	X	3
2.0 or more	4		0
Nitrate (mg/L)			
Observed Mean: 0.10			
At least 0.30	1		0
0.40 to 0.80	2		0
0.90 to 1.90	3		0
2.0 or more	4		0
Ammonia (mg/L)			
Observed Mean: 0.41			
At least 0.30	1		0
0.40 to 0.50	2	X	2
0.60 to 0.90	3		0
1.0 or more	4		0
Percent oxygen saturation at 5 feet			
Observed Value: 119%			
114% or less	0		0
115% to 119%	1	X	1
120% to 129%	2		0
130% to 149%	3		0
150% or more	4		0

Table 14. BonHomme Eutrophication Index Calculations for Sullivan Lake concluded (28 August 1989).

Parameter and Range	Range Value	Range Observed	Point Value
Percent of Water Column with at least 0.10 mg/L of DO			
Observed Value: 67%			
28% or less	4		0
29% to 49%	3		0
50% to 65%	2		0
66% to 75%	1	X	1
76% to 100%	0		0
Secchi Disk Transparency			
Observed Value: 2 ft.			
5 feet or less	6	X	6
Greater than 5 feet	0		0
Light Transmission at 3 feet			
Observed Value: 11%			
0% to 30%	4	X	4
31% to 50%	3		0
51% to 70%	2		0
71% or greater	0		0
Total Plankton from 5 foot Tow (#/L)			
Observed Value: 31,722			
Less than 4700/L	0		0
4701/L to 9500/L	1		0
9501/L to 19,000/L	2		0
19,001/L to 28,000/L	3		0
28,001/L to 57,000/L	4	X	4
57,001/L to 95,000/L	5		0
More than 95,000/L	10		0
Blue-green dominance	5	X	5
Total Plankton from Thermocline Tow (#/L)			
Observed Value: 31,722			
Less than 9500/L	0		0
9501/L to 19,000/L	1		0
19,001/L to 47,000/L	2	X	2
47,001/L to 95,000/L	3		0
95,001/L to 190,000/L	4		0
190,001/L to 285,000/L	5		0
More than 285,000/L	10		0
Blue-green dominance	5	X	5
Populations of 950,000 or more	5		0
			===
INDEX VALUE			36

range of TSI numbers for both sampling events were between 61 and 67. Lakes with TSI numbers between 60 and 70 are usually characterized by blue-green algae dominance, algal scums and macrophyte problems (Carlson 1979).

Table 15. Carlson Trophic State Index Calculations for Sullivan Lake.

SAMPLE DATE	SECCHI DISK (m)	TSI (SD)	CHLOROPHYLL (mg/m3)	TSI (Chla)	TP (mg/m3)	TSI (TP)
08/18/89	0.6	67	42.5	67	52	61
08/28/89	0.6	67	42.6	67	77	67

A comparison of the calculated TSI values for the first sampling event (18 August) shows that Secchi disk and Chla based values are equivalent and greater than the TP based value. This would indicate that light attenuation was dominated by algae, and the reservoir was phosphorus limited on the date of sampling (Carlson, 1983). The calculated TSI values for the second sampling event (28 August) shows the Secchi disk, Chla and TP based values to all be equivalent. This is an unusual occurrence (Carlson, pers. comm.), but still indicative of phosphorus limitation.

Both the BonHomme EI and the Carlson TSI classify Sullivan Lake as being in the intermediate stages of eutrophication at the time of sampling. The current EI number of 36, on a scale of 0 to 75, places the reservoir in Trophic Class Two. The Carlson TSI values are also characteristic of a reservoir moving through eutrophication. It should be noted that the data used to construct these indices are derived from only two sampling events and are only representative of lake conditions on those two days in late summer. Better representation of trophic state could be attained through increased lake monitoring throughout the summer growing season. Such high resolution sampling was beyond the scope of this investigation.

4.1.5 Sediment Sample Results

The results of the particle size analyses on sediment samples collected from Sullivan Lake are shown in Table 16. All samples were collected 30 November 1989. The sediment sample analysis indicates that sand was the dominant size class for all nine samples, ranging from 40% to 90% of the samples analyzed. Resuspension following a disturbance to the lake bottom would therefore be expected to have minimal and short-term effects on water clarity.

Table 16. Particle size analysis of Sullivan Lake sediments (30 November 1989).

SAMPLE NUMBER	% SAND	% SILT	% CLAY
1	78.0	4.0	18.0
2	88.0	8.0	10.0
3	86.0	10.0	4.0
4	90.0	10.0	0.0
5	40.0	40.0	20.0
6	70.0	10.0	20.0
7	70.0	10.0	20.0
8	78.0	10.0	10.0
9	78.0	12.0	12.0

4.1.6 Aquatic Vegetation

The aquatic plant survey documented eleven species of macrophytes (Figures 8a, 8b & 8c and Table 17). The predominant species included coontail (Ceratophyllum demersum) and pondweed (Potamogeton americanus), two submergent species. Water cress (Nasturtium officinale) and cattail (Typha latifolia), two emergent species, were also common. The majority of the aquatic plants were located in the shallow cove areas of the lake. Very few macrophytes were seen along the shoreline of the main body of the lake.

Table 17. Macrophyte species found in Sullivan Lake during late summer of 1989.

COMMON NAME	SCIENTIFIC NAME	CATEGORY
Water Milfoil	Myriophyllum spicatum	Submergent
Coontail	Ceratophyllum demersum	Submergent
Pondweed	Potamogeton americanus	Submergent
Sago Pondweed	Potamogeton pectinatus	Submergent
Bushy Pondweed	Najas flexilis	Submergent
Common Cattail	Typha latifolia	Emergent
Water Cress	Nasturtium officinale	Emergent
Quillwort	Isoetes sp.	Emergent
Duckweed	Lemna minor	Floating
Watermeal	Wolffia columbiana	Floating
Big Duckweed	Spirodela polyrhiza	Floating

The absence of macrophytes along the main shoreline is probably due to strong wave action from boat traffic, light limitation, or inadequate sediment texture or nutrient content. Steep-sided reservoirs do not

Figure 8a. Submergent macrophyte distribution in Sullivan Lake.

Figure 8b. Emergent macrophyte distribution in Sullivan Lake.

Figure 8c. Floating macrophyte distribution in Sullivan Lake.

support extensive development of macrophytes as most of the sediments are at a depth where light is limiting to growth. Additionally, sediments with high organic or inorganic (i.e. sand) content will not readily support macrophyte growth. Under these sediment conditions it is difficult for the root systems to obtain nutrients, and emergent macrophytes, with more extensive root systems, often replace submergent macrophytes (USEPA, 1988).

4.1.7 Shoreline Survey

A field investigation of the existing shoreline erosion was conducted on 7 November 1989. The extent of this erosion, and the height of the eroded banks is depicted in Figure 9 and Exhibit 1, along with selected reference depths from the bathymetric survey. The existing bank erosion is the result of wave action, from both boat traffic and wind, on the existing banks which are comprised of highly erodible soils (USDA, 1971). The severity of the bank erosion is greatest along the eastern shoreline in the south-central portion of the lake, where the eroded banks range from eight to 12 feet in height. This section of shore is in the direct path of wind generated waves (i.e. the fetch line) which undercut the toe of the existing bank. The survey documented 1600 linear feet of shoreline with 8 to 12 foot high eroded banks. Five to eight foot high eroded banks are found along a total of 3100 linear feet of shore. These eroded areas are typically points of land jutting into the lake, which take the full impact of boat wakes, and are found along sections of both the east and west shores of Sullivan Lake. Eroded banks of three to five feet in height are the most common, constituting 6100 linear feet of shore. These eroded areas are found primarily along the east shore in the southern lake basin. One to three foot high eroded banks were found along 3800 linear feet of shore. These eroded areas are found exclusively along the western shore, primarily in the south-central portion of the lake. Erosion in the lake embayments is minimal. Section six of this report addresses the shoreline erosion problem and recommended alternatives for stabilization.

4.2 WATERSHED SURVEY

The watershed survey examined both hydrology and land use information. The AGNPS model served as an important tool for integrating the effects of these factors on nutrient and sediment loading to the lake and interpreting their significance.

4.2.1 Hydrologic Results

With respect to lake restoration, the principal hydrologic parameter of interest in characterizing Sullivan Lake is the hydraulic residence time, defined as the length of time required for the entire volume of the lake to be replaced with "new' water from runoff and direct precipitation. This parameter defines how dynamic the system is and how responsive a lake will be to changes in nutrient loading.

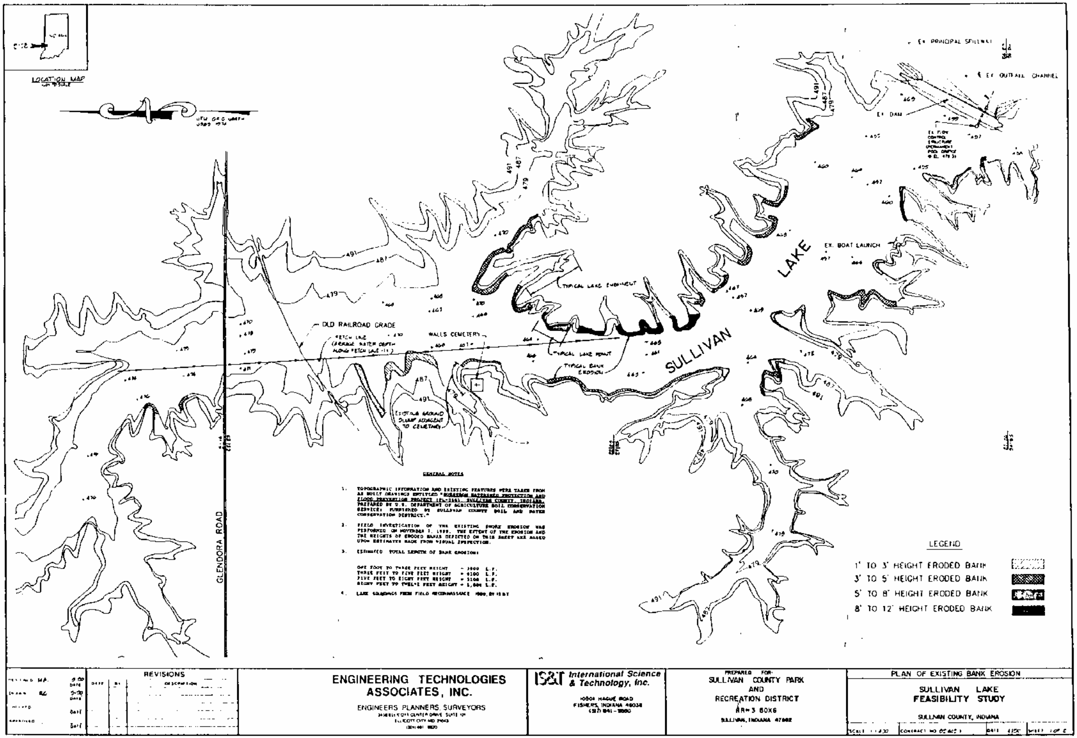

Figure 9. Shoreline Erosion

For this study, hydraulic residence time was computed as the ratio of lake water volume to the net annual inflow water volume. The formula used in calculating retention time (τ) is as follows:

$$\tau = \frac{V}{R+P-E}$$

Where:

τ = Hydraulic retention time (years)
V = Lake volume (acre-feet)
R = Average annual runoff (acre-feet/year)
P = Precipitation (acre-feet/year)
E = Evaporative losses (acre-feet/year)

Average annual runoff for the Sullivan Lake watershed was determined by multiplying the watershed area by the average annual runoff value of 13.58 inches (1.13 feet) reported for Busseron Creek near Carlisle, IN (USGS 1988).

Average annual rainfall for the Sullivan County area is 39 in/year (USGS, 1988). Thus, direct precipitative input to the lake was estimated to be 1648 acre-feet per year.

Evaporative losses from lake surfaces in southern Indiana are approximately 34 inches/year (Geraghty et. al., 1973) or approximately 1435 acre-feet for Sullivan Lake. Thus, there is a net increase of five inches (0.42 feet), or approximately 213 acre-feet of water added to the lake annually (i.e., the difference between direct precipitative input and evaporative losses).

The hydraulic residence time for Sullivan Lake was calculated to be 0.57 years (208 days), a relatively long retention period. Based on this calculation (i.e. 0.57 years), the entire volume of the lake would be replaced twice in just slightly over a one year period. Longer water residence times (i.e., 100 days to several years) provide ample time for algal biomass to accumulate, given sufficient nutrient concentrations (USEPA, 1988). From the perspective of lake restoration, Sullivan Lake is likely to have a relatively slow response to a reduction in external nutrient loading.

4.2.2 Land Use Characterization

One of the most influential factors governing the quality of a surface water body is the nature of land use in the watershed. Land use characterization within the Sullivan Lake watershed was critical in determining the input parameters for the AGNPS model. The land use categories and corresponding percentages of areal coverage are listed in Table 18. A land use map is presented in Figure 10.

Table 18. Land use percentages for the Sullivan Lake watershed.

CATEGORY	PERCENT OF WATERSHED
Water	6.0
Wetlands	1.1
Forest	14.2
Open	3.2
Pasture	3.1
Row Crops	53.0
Non-row Crops	2.7
Orchards	0.0
Feedlots	0.1
Low Density Residential	4.1
Medium Density Residential	10.8
High Density Residential	0.0
Commercial	0.4
Institutional	1.3
Bare/Unseeded Ground	0.0
Resource Extraction	0.0

The primary land use within the Sullivan Lake watershed was row crop agriculture, accounting for 53% of the total acreage. Blocks of row crops were found throughout the entire drainage basin, with a significant concentration located in the northern portion of the watershed. This large percentage of land presented the most significant potential source of sediment and nutrient loading to Sullivan Lake. Forested land constituted 14.2% of the watershed area and was found primarily along portions of the Sullivan Lake shoreline. Non-row crop agriculture comprised only 2.7% of the total watershed area.

Medium density residential use accounted for 10.8% of the watershed area. The three residential use categories combined, comprised 14.9% of the total area and were distributed with larger concentrations occurring along portions of the east and west shores of the reservoir, near the town of Shelburn to the north, and the city of Sullivan to the southwest of the reservoir.

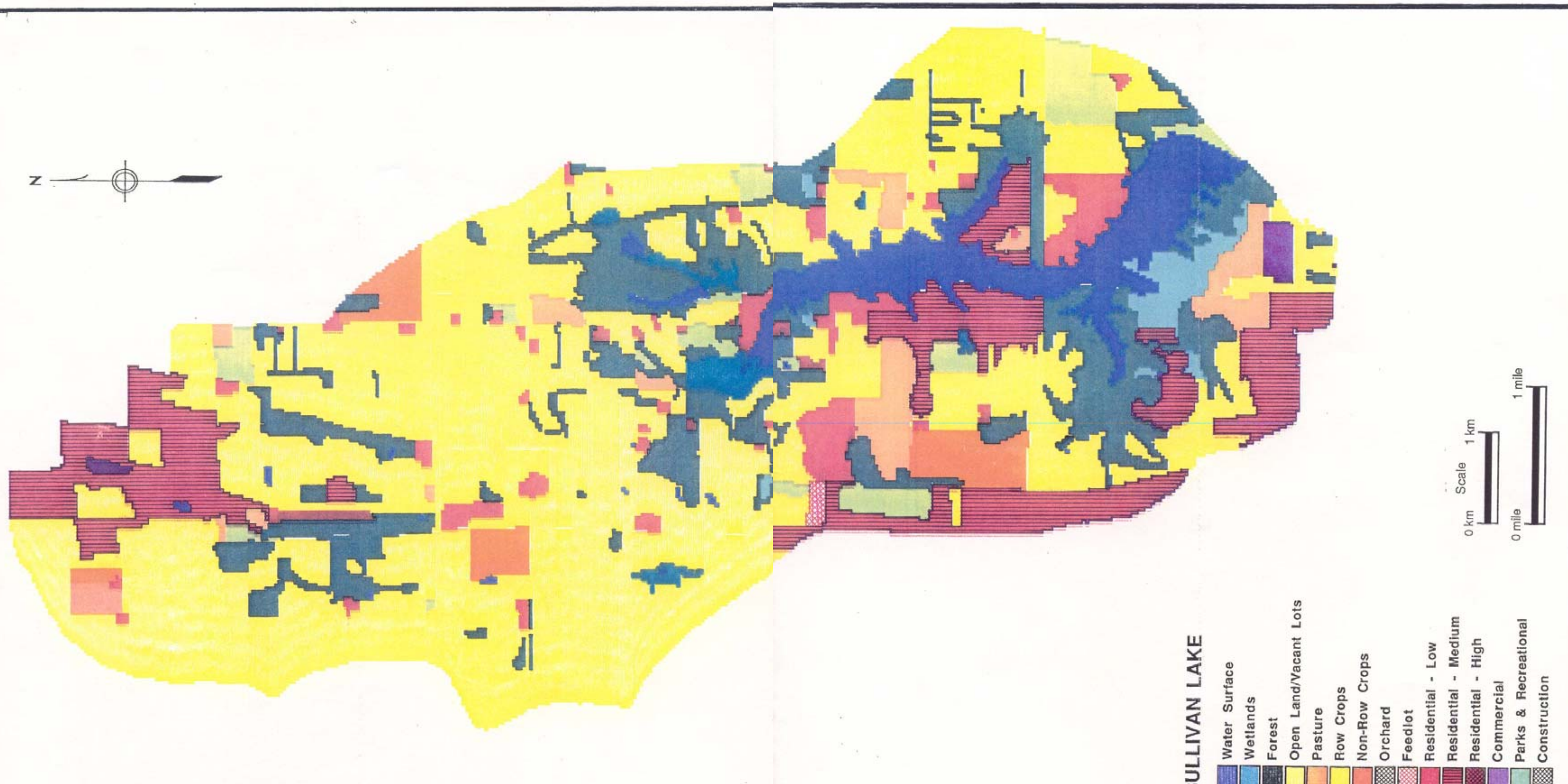

Figure 10. Land use map of the Sullivan Lake watershed.

4.2.3 Sediment/Nutrient Modeling

Prior to running the AGNPS model, it was necessary to divide the watershed into a grid of equal areas, called "cells". This grid was prepared by subdividing each 640-acre section of the USGS 1:24,000 topographic map, into eight 80-acre cells. These cells were then further subdivided to yield 16 40-acrecells per section. This method allowed referencing of cells to Range and Township boundaries. The AGNPS cell grid for the Sullivan Lake watershed is shown in Figure 11. The watershed contains 195 40-acre cells.

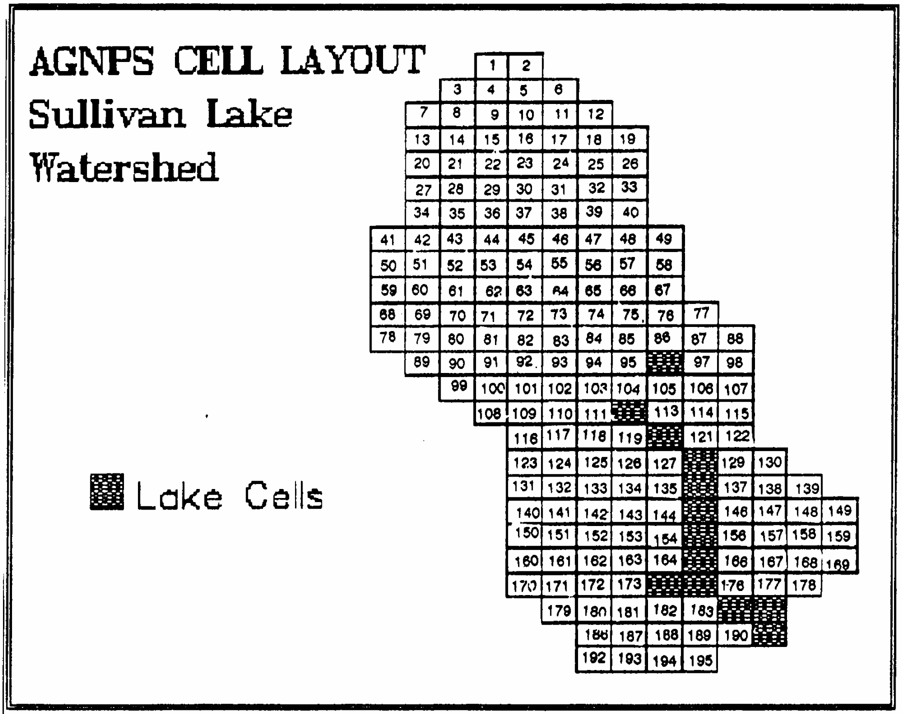

Figure 11. AGNPS cell grid for the Sullivan Lake watershed.

Data characterizing the physical features of the cells were utilized by the model to describe the sediment and nutrient contributions of each cell. This information was used to identify cells that were responsible for disproportionately high sediment and nutrient loading. Four categories of AGNPS output were evaluated in describing the pertinent export features: (1) sediment yield; (2) cell erosion; (3) nutrient loading, and (4) hydrology. The AGNPS model was run on one distinct scenario: a U.S. Weather Bureau defined, type two, two-year, 24-hour storm during the Spring growing season.

Sediment Yield and Erosion

Sediment yield from each AGNPS cell is the amount of sediment, in tons, that leaves a cell at its downstream edge. This yield represents the sediment generated inside the cell as well as the sediment generated upstream, and sediment deposition within the cell. Therefore, sediment yield is calculated as the sediment generated within the cell, plus upstream contributions, minus deposition.

Cell erosion refers to the amount of sediment that is produced by the storm event within an individual cell rather than the cumulative amount passing through the cell. It is useful in identifying the cells that experience the greatest amount of internal erosion. The most important factors contributing to erosion within a given cell are soil erodibility (i.e., K-factor) and land slope. Land use, water flow velocity, and the presence/absence of agriculture or unmitigated construction generally produce higher erosion losses than areas consisting of forests or wetlands. Watershed cells with comparatively high sediment yield and cell erosion are displayed in Figures 12 and 13, respectively.

The total sediment yield into Sullivan Lake during the modeled storm was calculated at 30,205 tons. The amount of sediment yielded from each cell in the watershed ranged from one to 1852 tons, with the greatest yield occurring within the Morrison Creek drainage area (e.g., cells #54, 63, 72, 82, 92 and #93) as seen in Figure 12. These cells represent the watershed area north of the reservoir, and are bounded on the west by U.S. Routes 41 and 150. A large portion of the sediment yield was contributed to Morrison Creek by its northeast branch, which drains the northeast portion of the watershed, including the town of Shelburn. The dominant land use within this area is row crop agriculture.

The cell with the highest sediment yield to Sullivan Lake, 1852 tons, was cell #92. The northern boundary of this cell is County Road 400 North, with U.S. Routes 41 and 150 as the western boundary. The 3,440 acre drainage area of cell #92 includes all high yield cells identified above, with the exception of cell #93. The amount of sediment entering cell #92, from upstream sources, was 1780 tons, a significantly greater amount than that generated within the cell (236 tons). Sediment deposition in cell #92 was eight percent. Cell #93 receives the outflow of #92 and is located directly east of that cell. Cell #93, characterized as wooded acreage, also had a high sediment yield (1713 tons). The majority of this sediment was generated from upstream sources, with a 12% sediment deposition rate in the cell. Cell #103 receives the outflow from cell #93, and is located immediately east of County Road 50 East. Morrison Creek flows through cell #103, a large wetland area, and enters Sullivan Lake within cell #112, approximately 1000 feet southeast of the southeast corner of cell #103. There is no sediment generated within this wetland cell. While the sediment yield from upstream sources is high (1830 tons), cell #103 has an 82% sediment deposition rate, effectively trapping the majority of the sediment generated upstream

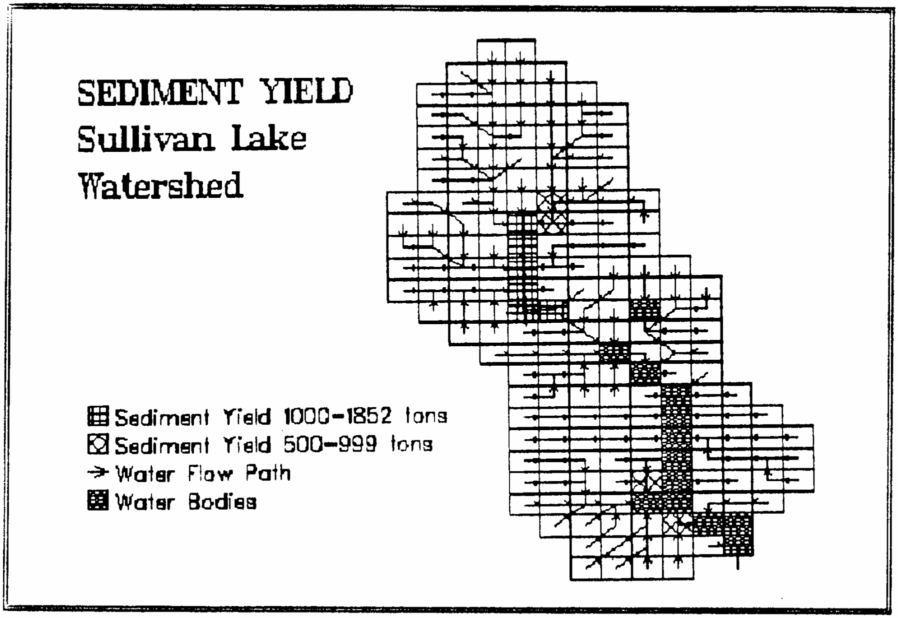

Figure 12. Sediment Yield for Sullivan Lake watershed.

and greatly reducing Morrison Creek's sediment load as it enters the northern part of the reservoir.

Additional areas of higher sediment yield are represented by cells #164 and #183. Both of these cells are located along the southwest shore of Sullivan Lake, and the yield from each was in excess of 500 tons. The majority of these sediments are generated from upstream sources. Cell #164 consists of wooded acreage up to the lake shore. The shoreline in this cell is characterized by one to three foot and three to five foot high eroded banks. Cell #183 is located within the Sullivan County Park and also includes a portion of the Sullivan Lake shore. This cell receives drainage from the adjacent golf course, and is characterized by three to five foot high eroded banks along the shore.

Cell erosion figures, generated by the AGNPS model for the 2 year, 24-hour storm ranged from no sediment production to 9.78 tons per acre. The average value for all cells in the watershed was 1.72 tons/acre. As indicated in Figure 13, cells exhibiting higher erosion rates (greater than 5 tons/acre) were generally located in areas west and northwest of Sullivan Lake. The highest rate of erosion (i.e., 9.78 tons/acre) was observed in cell #187. This cell is located southwest of the reservoir, immediately west of N. Foley St. and is bisected by Leach St., near the entrance to Sullivan County Park. The second

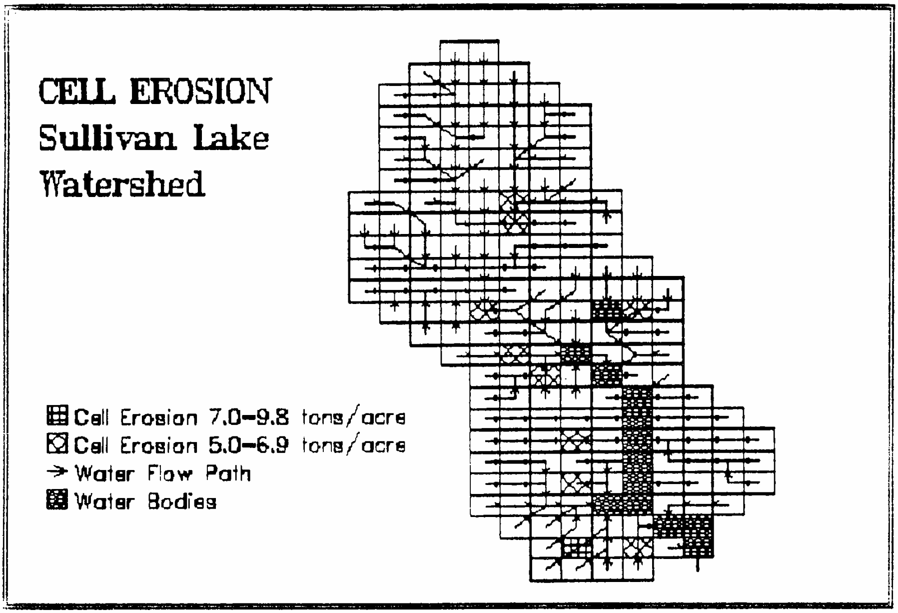

Figure 13. Cell erosion for Sullivan Lake watershed.

highest rate of erosion (i.e., 6.74 tons/acre) was found in cell #189. This cell is also located southwest of the reservoir, and is within the Sullivan County Park. Both of these cells had slopes of 5 to 6%, soil erodibility factors of 0.42, and land use characterizations of permanent meadow and agriculture.

Within the Morrison Creek drainage basin, cells #46, 55, 92, and #110 all displayed erosion rates greater than 5.0 tons/acre. The land use within these cells was primarily row crop agriculture. Cells #97, 118, 143 and #163 also had erosion rates in excess of 5.0 tons/acre. Cell #97 (6.0 tons/acre) includes a small pond just east of Jonay Pond. Runoff from this cell empties into a wetland with a high rate of sediment deposition (87%). Erosion from cells #143 and #163 (6.7 tons/acre and 5.4 tons/acre, respectively) would have a greater effect on the lake. Both cells have relatively direct paths to the lake and low rates of deposition. Land slopes of these cells ranged from 3.7% to 4.4%, and soil erodibility factors ranged from 0.37 to 0.43.

Nutrient Loading

The AGNPS model supplied estimates for both soluble and sediment-bound nitrogen and phosphorus concentrations in runoff from the watershed. Soluble forms of both nutrients are readily available to aquatic vegetation and phytoplankton, whereas the sediment-bound fractions are not likely to have an immediate effect. Watershed cells exporting relatively high nitrogen and phosphorus loadings are displayed in Figures 14 and 15, respectively.

Nitrogen: Using the cumulative data generated by the AGNPS model, it was possible to ascertain the cell yield of total nitrogen (i.e., the sum of soluble N and sediment-bound N) from the watershed during the design storm. Excessive soluble nitrogen loadings occurred exclusively in the southwest portion of the watershed. Excessive sediment-bound nitrogen loadings occurred in both the northern and southern portions of the watershed (Fig. 14). The total nitrogen input from the entire Morrison Creek watershed (3760 acres) was 17,747 pounds or 4.72 pounds/acre. Approximately 90% of this amount, 16,055 pounds, was in the form of soluble nitrogen. The much greater soluble fraction of the total nitrogen loading from the Morrison Creek sub-basin is most likely due to the presence of a wetland just upstream of the reservoir (cell #103). The sediment-bound component of the total nitrogen loading would be expected to decrease as sediment is trapped within this cell. A comparison of nitrogen loading at the outlet of the cell just upstream of the wetland with the outlet of the wetland cell shows a 74% reduction in sediment-bound N, but only a 3% reduction in soluble N. A total nitrogen loading of 8751 pounds was calculated for the drainage basins of the five unnamed tributaries to Sullivan Lake. These drainage basins constituted a total area of 1560 acres. An additional 9299 pounds of nitrogen loading, occurring from overland runoff, was received from lands immediately adjacent to the lake. These lands, 1560 acres, include the Sullivan County Park, and the residential and agricultural areas along the east and west shores of Sullivan Lake.

Soluble nitrogen generated within individual cells ranged from 0.18 pounds/acre to 7.73 pounds/acre. Values of 7.73 pounds/acre were observed in cells #123, 140, 150, 160, 170, 179 and #180. These cells, with the exception of cell #180, represent urban areas with a minimum of 21% impervious surfaces within each cell, and are located immediately east of Section Street on the west border of the watershed. Cell #180, located immediately east of cell #179, is situated within the Sullivan County Park boundary.

Sediment-bound nitrogen generated within individual cells ranged from 0.17 to 8.25 pounds/acre. The highest value was observed in cell #163, a cell characterized by row crop agriculture, located just west of the reservoir and on the north border of the Park. This loading can be explained by the predominantly agricultural land use and the moderately high sediment erosion rate of this cell.

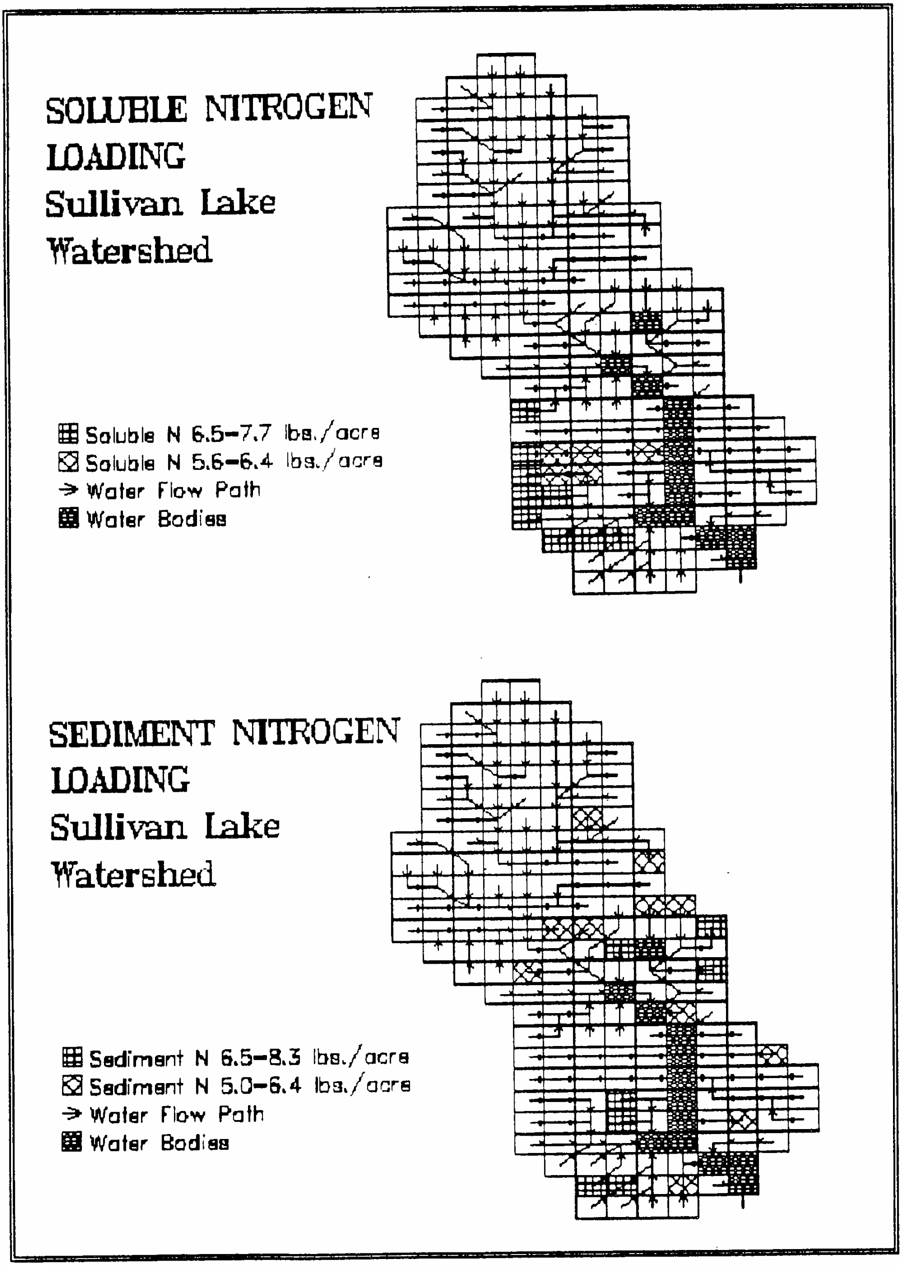

Figure 14. Soluble and sediment nitrogen loading for Sullivan Lake watershed.

Phosphorus: Phosphorus loading to Sullivan Lake was also modeled using AGNPS. The data generated was used to ascertain the cell yield of total phosphorus during the design storm. As with the nitrogen loading, excessive soluble phosphorus loads occurred exclusively in the southwest portion of the watershed, while high sediment-bound phosphorus loads were found in both the northern and southern portions (Fig. 15). The total phosphorus (i.e., both soluble and sediment-bound P) input from the Morrison Creek watershed was 4211 pounds, or 1.12 pounds per acre. Of this amount, approximately 79% (3346 pounds) was in the soluble form. As was the case with total nitrogen, the presence of a wetland just upstream of the reservoir greatly reduced the sediment-bound fraction of total phosphorus, but had little effect on the soluble fraction. Sediment-bound P loading at the outlet of cell #103 was 0.23 pounds/acre, a 74% reduction of the loading rate immediately upstream. Soluble phosphorus was reduced just over 3% by the wetland area. The total phosphorus loading from the Morrison Creek sub-basin was reduced by 34% as a result of the wetland in cell #103. A total phosphorus input of 2567 pounds was calculated for the drainage basins of the five unnamed tributaries to Sullivan Lake. An additional 3055 pounds of phosphorus loading was contributed from lands adjacent to the reservoir.

Soluble phosphorus values generated by the model for the design storm ranged from 0.01 to 1.65 pounds/acre. Values of 1.65 pounds/acre were found in cells #123, 140, 150, 160, 170, 179 and #180. These cells also exhibited the highest soluble nitrogen values.

Sediment-bound phosphorus exhibited a range of 0.09 to 4.13 pounds/acre. Cell #163 generated the highest value. This 40-acre area also generated the highest sediment-bound nitrogen value. Cells #88 and #95 showed sediment-bound phosphorus production rates in excess of 3.5 pounds per acre. In all three cells, row crop agriculture is the primary land use, and land slopes within the cells are in excess of 3.3%.

Hydrology

The AGNPS model was also used to examine the hydrologic inputs to Sullivan Lake for the design storm conditions. Runoff values for the individual cells ranged from 0.84 to 2.45 inches. Watershed cells producing runoff greater than or equal to 80% of the peak runoff observed (i.e., 1.96 inches) are displayed in Figure 16.

The area producing the greatest runoff volume, 2.45 inches, was cell #195. The cell is located southwest of Sullivan Lake and includes a portion of the County Farm. Washington Street and County Road 150 East are the south and east borders of this cell. Cells #115, 131, and #178 all produced a runoff volume in excess of 2.00 inches. The areas are primarily fallow agricultural land. Two woodland areas, cells #35 and #87, produced the least runoff volume for the watershed.

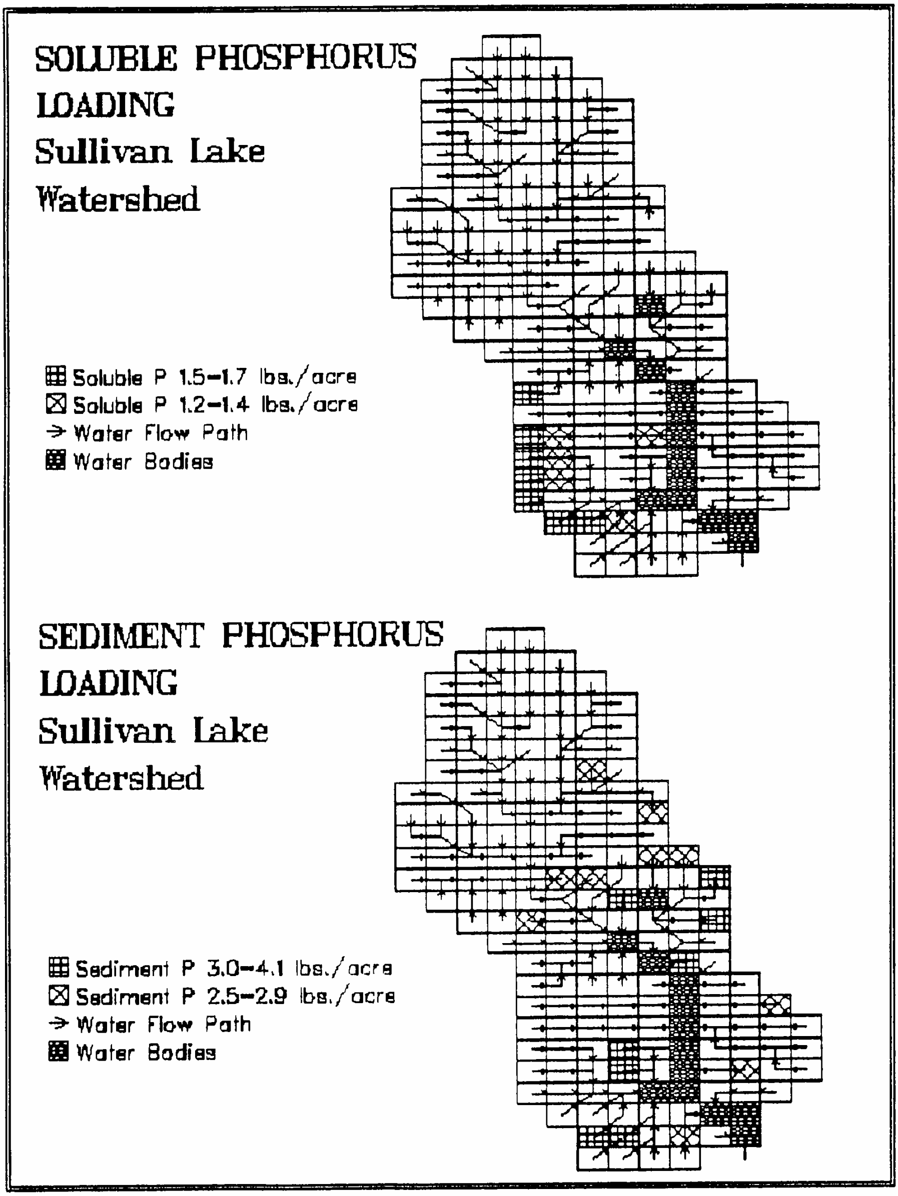

Figure 15. Soluble and sediment phosphorus loading for Sullivan Lake watershed.

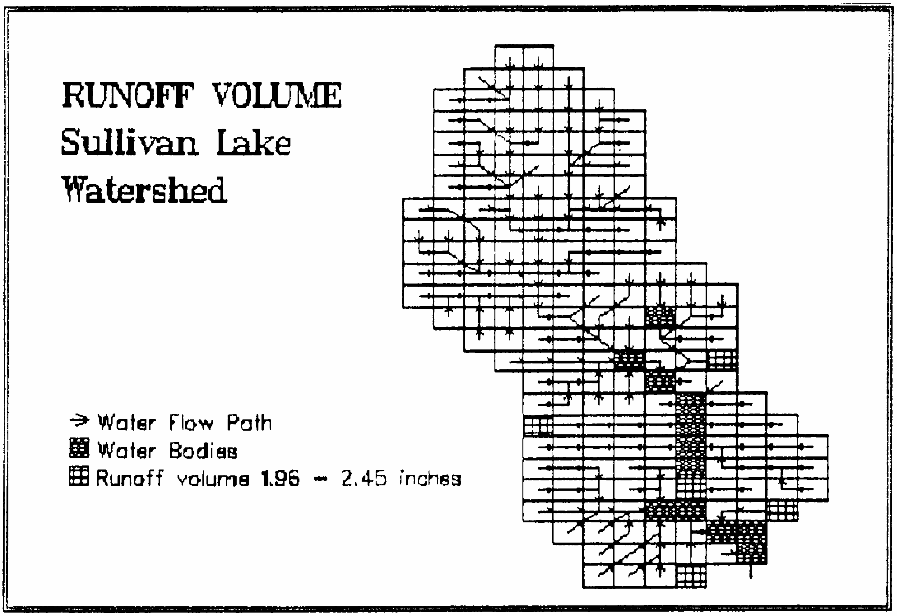

Figure 16. Runoff volume for Sullivan Lake watershed.

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SECTION 5. SEDIMENT AND NUTRIENT CONTROL TECHNOLOGIES

Based on the results of the AGNPS modeling, the main source of watershed inputs of sediments and nutrients to Sullivan Lake is the Morrison Creek tributary system, which drains over 4,000 acres of primarily agricultural lands to the north of the reservoir. Cells containing disproportionately high sediment and/or nutrient loading were also identified near the towns of Sullivan and Sherburn, and within the Sullivan County Park. Although the AGNPS model did identify problem areas within the watershed, sources of the problems are much more difficult to identify. Agricultural activities in the upland areas, potential septic leachate from lakeshore residences, and fertilizer and animal waste runoff are all likely to impact the lake in varying degrees. This study found that Sullivan Lake is not currently experiencing significant eutrophication, however the high total phosphorus concentration near the lake bottom, and the rapid reduction in dissolved oxygen levels below approximately 15 feet suggest nutrient enrichment from the watershed. The lake is likely to move from a Class II to a Class III lake, i.e., become more eutrophic, in a relatively short period of time. Advancing eutrophication in Sullivan Lake can be slowed considerably through the widespread application of best management practices (BMP's) within the watershed. The following section is a discussion of the types of BMP's that would be expected to have the greatest role in reducing nutrient concentrations and sediment inputs to the lake and receiving streams. Section 5.1 focuses on erosion control techniques that will reduce both nutrient and sediment transport to streams. The techniques described are primarily aimed at reducing loading from agricultural areas, however urban erosion control is also discussed. Section 5.2 provides an overview of BMP's for nutrient reduction specific to agricultural areas. This section also includes recommended maintenance procedures applicable to the Sullivan Lake Park. With the exception of the obvious need for shoreline stabilization (see Section 6), in-lake restoration methods are not deemed necessary at this time. However, Section 5.3 discusses both weed harvesting and dredging should the need arise for either of these management tools in the future.

5.1 EROSION CONTROL

This section provides an overview of agricultural BMP's that have been developed for erosion control on cropland, pastures, and streambanks. Within the Sullivan Lake watershed, erosion control is especially important on lands adjacent to or near Morrison Creek or its tributaries. The AGNPS model showed that the wetland near the mouth of this stream is critical in reducing the concentration of sediment bound nutrients, and the sediment load itself from this sub-basin. Implementation of erosion control practices will act to prolong the effectiveness of the wetland.

Although not classified specifically as lake restoration techniques, erosion control practices maintain productivity on the land, reduce costs of fertilizers and pesticides, and ultimately benefit receiving streams and lakes. The Soil Conservation Service has published design criteria for a variety of BMP's, including those discussed below. This agency has and will continue to provide guidance to individual farmers and land owners in selection and implementation of BMP's. The following summary is drawn from a manual developed by the EPA, in conjunction with the North American Lake Management Society, entitled Lake and Reservoir Restoration Guidance Manual, published in 1988.

5.1.1 Agricultural Erosion Control

Conservation Tillage. Erosion in agricultural areas of the watershed can be significantly reduced by conservation tillage practices. The objective of conservation tillage is to protect soil from wind and water erosion by increasing the amount of crop residue. No till farming, where the topsoil is left essentially undisturbed year round, and minimum tillage are forms of this BMP. The effectiveness of these practices in reducing sediment loss and runoff is considered fair to excellent, depending on the degree of tillage reduction (U.S. EPA, 1988). Phosphorus in runoff can be greatly reduced with conservation tillage, however nitrogen concentrations are largely unaffected. In fact, total nitrogen and herbicide concentrations may increase in groundwater as a result of no till practices, a potential negative side effect. Fertilizer management and integrated pesticide management should accompany conservation tillage practices.

Contour Farming/Stripcropping. Contour plowing and contour stripcropping are effective in reducing soil loss on farm land with a 2-8 percent, and 8-15 percent slope, respectively. Both practices require plowing along the natural contours. In stripcropping, grasses or other close growing crops are planted between row crops, such as corn or soybeans.

Streamside Management/Buffer Strips. Vegetation planted between a stream and plowed field (a buffer strip) is extremely effective in reducing both nutrient and sediment inputs, and in protecting riparian habitat. This is a very cost effective practice. Once established a buffer strip will maintain itself indefinitely. Parameters that determine the effectiveness of filter strips include filter width, slope, vegetation type, and application rate of fertilizers.

Other Erosion Control Practices. Management of pasture lands to prevent overgrazing, thereby reducing soil compaction and runoff, is important in an overall sedimentation control plan. Stream banks should be fenced to prevent access to cattle and destruction of soft banks. Crop rotation, terracing, and soil stabilization are also effective in reducing sediment inputs to streams.

5.1.2 Urban/Residential Erosion Control

Control of erosion due to development or construction activities must be a component of a watershed wide approach to reduce sedimentation in Sullivan Lake. Factors that influence the type and amount of erosion include the nature and extent of vegetative cover, topography; and the frequency, and intensity of rainfall events.

Vegetative cover plays a critical role in controlling erosion by absorbing the impact of falling rain, holding soils together, increasing the retention capacity of soils, and slowing runoff velocity. Evapotranspiration by plant cover also aids in reducing erosion by removing water from soils between rainfall events.

Topographic characteristics (i.e., slope, size, and shape) of the drainage basin have a strong influence on the amount and rate of runoff. Changes to site topography resulting from development can have a significant impact on the quantity of runoff, and therefore sediment, that is generated.

The characteristics of surface and subsurface soils are fundamental to the resistance of soils to erosive forces, and to the nature of the sediment that results from erosion. Soils with high sand and silt content are normally the most highly erodible. Increasing organic and clay content result in decreased erodibility, however these soils are more easily transported.

In general, the following practices may be applied to control of erosion due to land development activities within the Sullivan Lake watershed. These practices are not presented in detail. Two excellent source of further information specific to Indiana is the Hoosier Heartland Resource Conservation and Development Council's Urban Development Planning Guide (HHRCDC, 1985), and a model erosion control ordinance (HERPICC, 1989) that may be used at both the City and County levels.

Phased Construction. Phasing construction activities minimizes the extent of land disrupted at one time, reducing the sediment load to a receiving stream or lake during a given storm event. If multiple structures are to be built over an extended period, the entire area slated for development may not have to be cleared at once.

Road Stabilization. Several practices are available to minimize erosion and sediment transport due to traffic in construction areas. These include stabilization of freshly graded road surfaces with gravel and installation of gravel pads at entrances to construction sites. The latter serve to reduce the amount of sediment carried off-site on tires of construction vehicles.

Sediment Barriers. Various types of barriers may be placed in the path of runoff to detain sediment and decrease flow velocities. These barriers, consisting of hay or geotextile filter fabric, are placed across or at the toe of slopes. Sediment barriers are also effective in protecting storm drain inlets from construction site runoff.

Sediment Traps and Basins. Temporary basins may be constructed to contain flows long enough for sediment to settle out. These basins are characteristically simple, often consisting of a small pond formed by an earthen dike, with a gravel lined outlet.

Establishment of Vegetative Cover. Planting of fast growing grasses and other plants provides a means for quickly stabilizing disturbed areas. The choice of plant type will depend on the intended permanency of the cover. Mulching with straw and other fibrous materials will aid in establishment of protective vegetation. This in itself will reduce erosion and runoff on disturbed areas.

For future developments in the Sullivan Lake Watershed, an erosion and sediment control plan should be developed to address the potential problems resulting from the particular activity. The plan should clearly present the anticipated erosion and sedimentation problems that are likely to result, and the measures that will be taken to mitigate them. Both narrative and graphical sections should be included. The narrative section should include the following:

- Brief description of the project
- Existing conditions (physical features, slope, etc.)
- Description of adjacent areas that may be impacted
- Summary of soil characteristics Identification of problem areas (high slope, erodible soils, etc.)
- Erosion and sediment control measures to be used
- Description of post construction stabilization and practices, including measures to control storm water runoff
- Storm water runoff concerns and impacts
- Inspection and maintenance schedules planned
- Calculations used in design of basins, waterways, and other structural controls.

Graphical materials in the site plan should provide the necessary maps and related materials, including:

- Vicinity map showing site location
- Current elevation contours
- Existing vegetation types and locations
- Soils
- Critical erosion areas
- Existing drainage patterns
- Proposed contours after grading
- Limits of clearing and grading
- Location of erosion and sediment control practices
- Detailed drawings of structural practices to be used

The final plan should be subject to approval of a county or local planning board or similar group, and should provide comprehensive documentation of the erosion and sediment control strategies to be applied in the development of the site.

5.2 WATERSHED NUTRIENT REDUCTION

In addition to causing nuisance algae and other water quality problems in the lake, excessive nutrient loading can result in groundwater contamination and human health effects. Erosion control measures will decrease sediment bound nutrient loading, however a reduction in the transfer of soluble fractions of phosphorus, and particularly nitrogen must also be a management priority. Animal wastes and fertilizers are two key sources of soluble nutrients in the watershed. The section below focuses on BMP's designed specifically to reduce soluble inputs. Animal wastes from feedlots and confinement areas, application of animal manures as fertilizers, and commercial fertilizers themselves are primary sources of soluble nitrogen and phosphorus. BMP's for pasture management and stream protection are also described.

5.2.1 Animal Production and Keeping

The need for confinement of animals in feed lots or holding facilities, as opposed to open pastures, results in highly concentrated runoff. Summaries of several BMP's that have been designed to address problems associated with confinement areas are presented below.

Roofing. On the average, the Sullivan Lake watershed receives over three feet of rainfall per year. This means that for each acre of open confinement area, over a million gallons of contaminated water are generated on an annual basis. Washdown water may equal this amount. Roofing confinement areas allows separation of clean runoff from contaminated slab runoff. Roof gutters and a water collection system greatly reduce the amount of water that must be treated.

Location. The amount of pollutants entering a stream decreases with distance from the source. The distance where zero pollution enters a waterway has been estimated to be 98 to 393 feet, depending on soil characteristics, grass type, and density of cover (Novotny and Chesters, 1981). Confinement areas should be built up and graded away from a ditch or stream. Animals should be fenced no closer than the top of the grade. The ditch slope should have a grass cover, and the runoff from the storage facility should be retained.

Washdown Water. BMP's for the use of washdown water focus on recycling and reduction in the quantity of water used. Substituting higher water pressure for volume and scraping manure prior to hosing minimizes water usage.

Manure Storage Lagoons. Farms with a limited capacity for liquid manure storage must frequently spread the lagoon contents on pasture land to prevent overflow. This often results in ponding of the liquid waste during periods when the ground is saturated, e.g., following snowmelt in the spring. Manure applied under these conditions is likely to flow off of the field and into a waterway. Installation of a solids separator ahead of the lagoon increases the capacity of the lagoon and lengthens the period between cleaning. In addition, odor problems are reduced.

5.2.2 Manure Application to Pastures

Although no data were collected for the Sullivan Lake watershed concerning manure application, it is probable that a large percentage of manure that is produced from animal production is returned to the land. There is general agreement that manure can and should be used in crop production to increase yields and fertility. However, water quality degradation will occur without proper management of manure application. Proper timing of application (i.e., during non-saturated conditions), application to land with minimal slope, addition of manure in quantities equal to crop requirements, and avoidance of soil compaction during the application process will minimize problems due to manure application.

5.2.3 Fertilizer Management

Application of fertilizers in quantities equal to crop needs will greatly reduce nutrient enrichment of aquatic resources due to agricultural operations. Reducing the loss of nutrients to the groundwater or air is dependent on proper soil testing, and establishment of realistic yield goals. Knowledge of the contribution that legumes, manure, and crop rotation make to soil nitrogen and phosphorus levels is critical to determining proper application rates.

Nitrogen: Over application of nitrogen has been recognized as a significant problem in agricultural areas throughout the country. Nitrate in soils in excess of crop requirements results in groundwater contamination, as well as increasing eutrophication of surface waters. Although some degree of over-application is necessary given significantly less than 100% uptake efficiencies, current research on this problem points to a lack of consideration of alternative sources of nitrogen, such as manure or alfalfa, in calculating the quantity of fertilizer necessary for a given yield (Granatstein, 1988). Nitrogen "credits", i.e., a reduction in the amount of nitrogen necessary due to carryover from previous crops (legumes) or to crop rotation result in both cost benefits to farmers and improved water quality. Examples of nitrogen credits, in terms of pounds/acre N for previous legume crops, are shown in Table 19. This information is taken from material published in a University of Wisconsin Extension Bulletin (Granatstein, 1988). The Sullivan County SCS can provide additional information on nitrogen management.

Phosphorus is not as mobile a nutrient as nitrogen, and will tend to remain in the soil for longer periods of time. Erosion will reduce soil phosphorus levels, however in many cases, phosphorus levels will have built up over the years, and continued, or "maintenance applications", may not be economically justified (Granatstein, 1988).

Timing of application is also a key factor in reducing the quantity of fertilizers that reach ground or surface waters. In general, application in the fall results in significant runoff and loss during the non-growing season. Spring pre-plant application is recommended.

Table 19. Nitrogen credits for previous legume crops.

CROP	NITROGEN CREDIT
FORAGES	
Alfalfa	40 lb. N/ac plus 1 lb. N/ac each percent legume in stand.
Red Clover	Use 80% of alfalfa credit.
Soybeans	1 lb. N/ac for each bu/ac of beans harvested up to a max. credit of 40 lb. N/ac.
GREEN MANURE CROPS	
Sweet Clover	80-120 lb. N/ac.
Alfalfa	6-100 lb. N/ac.
Red Clover	50-80 lb. N/ac.
VEGETABLE CROPS	
Peas, snapbeans, lima beans	10-20 lb. N/ac.

5.2.4 Septic Systems

Homes on septic systems within the watershed, and more importantly, on the lakeshore, may be a source of nutrients. No data were collected during the Feasibility Study that indicated this, however a detailed septic system survey was beyond the scope of the project. The following paragraphs offer general guidance on installation, use, and maintenance of septic systems.

Proper Location. The features governing appropriate placement of septic systems include proper soils and adequate buffer distances between the drain field and sensitive areas. Information is available from both the SCS and USGS concerning the suitability of various soils and geologies for drain field construction. These agencies should be consulted prior to installing any new system. The Indiana Department of Environmental Management should also be contacted to determine the most recent limitations concerning minimum distance of the drain field from drinking supplies, lakes, drainage ditches, etc.

Regular Inspection and Maintenance. A septic tank should be inspected at least once per year to assess the rate of solids accumulation. If these materials build up, they will be transferred with the waste to the drain field, resulting in clogged soil pores. This condition results in a reduction of permeability, and eventually construction of a new drain field. Septic system maintenance should involve inspection of "Tee-joints" and distribution boxes, since these parts are especially prone to shifting that can lead to uneven dispersal of waste water into the drain field. Material removed from the tank should be discharged at a treatment plant. Periodic inspection and pumping will avoid this expense.

Drain Field Protection. Trees should not be allowed to grow on top of the drain field. Tree roots can penetrate the field, diminishing its efficiency. Vehicular traffic should also be prevented, since this will cause compaction of the leach field soils.

Proper Use. Solids, greases, or toxic materials should not be disposed of in septic systems. Solids, such as paper towels, disposable diapers, add to the overall load of the system, decreasing efficiency and increasing maintenance costs. Fats, oils, and greases can solidify in the system and create blockages. Toxic materials (e.g., paints, motor oil, pesticides) are not decomposed by septic systems and can leach out into groundwater, contaminating wells and eventually reaching lakes and streams. In addition, these materials can kill the beneficial bacteria responsible for decomposing normal septic system wastes.

Additives. Authorities agree that under most circumstances, chemical and biological additives are not needed to accelerate decomposition in the septic field. Under extreme use situations however, these additives may be helpful. Caution must be observed when using these products since some additives will actually inhibit decomposition. Products containing more than one percent of the following chemicals should not be used:

- **Halogenated hydrocarbons:** trichloroethane, trichloroethylene, methylene chloride, halogenated benzenes, carbon tetrachloride;

- **Aromatic hydrocarbons:** benzene, toluene, naphthalene;

- **Phenol derivatives:** trichlorophenol, pentachlorophenol, acrolein, acrylonitrile, benzidine.

A good reference with information on septic system design and maintenance is found in Perkins (1989).

5.2.5 Sullivan Lake Park Grounds Maintenance

The following paragraphs provide a summary of maintenance procedures to reduce nutrient inputs to Sullivan Lake from the Sullivan Park facility. No data were collected during this study that indicated a problem specific to this park, however, the following "common sense" procedures will minimize nutrient concentration in runoff from the Sullivan Park campground. Much of the material in this section is also applicable to homeowners.

Grass and Leaves. Grass clippings should be allowed to remain on the lawn following mowing unless excessive thatch build-up occurs. This will reduce the need for artificial nutrients. In addition, this will have a beneficial effect on the nationwide waste disposal problem, as bagged grass or leaves comprise 15-20% of all substances placed in landfills (Hugo, 1990). Raked leaves should not be disposed in or near the lake or its tributaries. Instead, they should be bagged and transported to a compost area away from any water flow path. If a compost area is used, runoff should not be allowed to reach the lake or tributaries.

Trash Receptacles. The number of trash cans and dumpsters should be sufficient to handle all trash deposited between collections. The containers should be cleaned with plain water directed from a spray nozzle. Disinfectants should be used sparingly and not allowed to drain onto the ground. Rinse water containing disinfectant must be properly disposed of.

Holes should not be drilled in the bottom of trash barrels to afford better drainage. Water percolating through these containers is high in nutrient and bacterial content, and should be avoided. Trash cans should be covered and not left open. Spring-loaded lids are recommended, and open topped drums should be avoided. Rusty receptacles should be replaced promptly. Trash cans should be placed as far as possible from the lake.

Fertilizers and Chemicals. Application of fertilizers should be avoided or minimized. These products will enhance the growth of algae and macrophytes in the lake if they are present in runoff. Application of other chemicals, such as pesticides and herbicides, should be carefully controlled and avoided if possible. Alternatives to chemical treatment should be investigated.

Automobile Traffic. The exhaust from internal combustion engines is high in metal, hydrocarbon, and nutrient content. So called "tailpipe drippings" are a major source of nutrients in urban watersheds. Drains and waterways along roads and parking lots should be situated so as not to channel runoff directly into the lake or its tributaries. Ideally, stormwater runoff should be routed to a treatment facility (or holding pond). If this is not feasible, runoff should be routed across large, vegetated areas prior to being allowed to enter the lake or its tributaries.

Education Centers. Visitors to Sullivan Lake Park should be educated on issues surrounding the lake and its care. Broad-based nature exhibits or storyboards on specific problems, such as why fisherman should not clean their catch in or near the lake (entrails can lead to elevated bacteria counts and reduction in dissolved oxygen) would promote understanding of water quality issues.

5.3 IN-LAKE RESTORATION

The most immediate problem affecting Sullivan Lake is severe bank erosion. Section 6 of this report addresses this issue specifically and describes detailed mitigation techniques. At this time, problems associated with nutrient enrichment and sedimentation due to watershed inputs or from the lake sediments are not considered serious enough to warrant in-lake restoration measures in addition to shoreline stabilization. However, a brief description of two common lake management tools, dredging and weed harvesting, that may be necessary in the future, is presented below. Further information on these techniques, and on a wide range of other lake restoration methods can be found in a book entitled Lake and Reservoir Management (Cook et al., 1986). Sullivan Lake has a relatively long retention time (208 days), which means that it will be relatively slow to respond to changes in external nutrient loading. However, this is beneficial for many lake management techniques, particularly those designed to reduce nutrient generation from the sediments, such as alum addition. It must be realized that in-lake techniques, particularly those designed specifically to reduce nutrient concentrations, will be short-lived without corresponding measures in the watershed.

5.3.1 Dredging

Dredging, or wet sediment removal, involves either scooping up bottom material in buckets that are subsequently emptied into a barge or truck for transport to a disposal area, or pumping the material as a slurry through a pipe to a constructed sedimentation basin for dewatering.

Bucket dredges consist of a dragline or backhoe operated from a barge platform, accompanied by a second barge to hold the dredge material. When the second barge is full, it is moved to shore where the spoil is transferred to a truck for disposal. The advantages of this method include a high solids content of the dredge material, and a high degree of maneuverability of the dredge. Disadvantages include excessive turbidity at the dredge site and a relatively slow rate of removal.

Hydraulic dredges are the most common machines used in wet dredging operations. The dredge consists of a cutter head mounted on the end of a suction pipe suspended from a barge. As the cutter head dislodges sediment, the loosened material is sucked into the pipe in the form of a slurry. The slurry pipe extends from the barge to a disposal site, where a settling basin is required to dewater the material.

The advantages of hydraulic dredging include relatively high removal rates, high cost efficiencies, and minimum impact on the shoreline. Disadvantages include the need for containment basins, which often require several acres of land near the dredge site, relatively high turbidity, and the need for a suitable pipeline route from the lake to the dewatering basin. Maximum pumping distance with this technique is approximately one mile. Greater distance is possible, however in-line pumps are required which greatly increase the cost of the operation.

5.3.2 Weed Harvesting

A reduction in internal nutrient loading through weed harvesting is an indirect benefit of this lake management tool. The direct benefits of aquatic plant harvesting relate primarily to increased recreational use of the lake. However, nutrient removal and protection of the pelagic zone from nutrients released during macrophyte decay may also result from harvesting. If nutrient income is low to moderate and weed density is high, as much as 50 percent of the net annual phosphorus loading could be removed through intensive harvesting (USEPA, 1988). Mechanical weed harvesting, however, is energy and labor intensive. Additionally, plants may fragment and spread the infestation. It is recommended that floating barrier systems be utilized during harvesting to curtail the spread of buoyant plant fragments, and aid in their collection.

The objective of weed harvesting is to cut and remove nuisance growths of rooted aquatic plants and associated filamentous algae. The most common means of harvesting is accomplished through the use of a mechanical weed harvester; a maneuverable, low-draft barge designed with one horizontal and two vertical cutter bars, a conveyor to remove cut plants to a holding area on the machine, and another conveyor to rapidly unload plants. Harvesters vary in size and storage capacity, with cutting rates ranging from about 0.2 to 0.6 acres per hour depending on the size of the machine. Disposal of the cut materials is usually not a problem. Because aquatic plants are more than 90 percent water, their dry bulk is comparatively small. Additionally, farmers and lakeshore residents will often use the cut weeds as mulch and fertilizer.

Most harvesting operations are effective at producing a temporary relief from nuisance plants, and in removing organic matter and nutrients. In some cases, however, plant regrowth can be very rapid (days or weeks). Conyers and Cooke (1983) and Cooke and Carlson (1986) found that a slower method of lowering the cutter blade approximately one inch into the soft sediments would produce a season-long control of milfoil by tearing out the plant roots (USEPA, 1988). This harvesting method is only effective when sediments are soft and the length of the cutter bar (usually 5 - 6 ft.) can reach into the mud.

Harvesting costs in the Midwest range from $135 to $300 per acre (1987 dollars). Costs for a particular project relate directly to machine cost, labor, fuel, insurance, disposal charges, and the amount of machinery downtime (USEPA, 1988).

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SECTION 6. SULLIVAN LAKE SHORELINE EROSION

The following section of the report addresses the problem of shoreline erosion at Sullivan Lake. This Feasibility Study, which was initiated in large part to quantify the erosion problem at Sullivan Lake and provide alternative solutions, documented a total of 14,600 linear feet of shoreline that is currently in an eroded condition. The magnitude of existing erosion is presented in Exhibit 1, a 1:400 scale map of the entire lake showing four classes of erosion severity: Class 1; one to three feet in height, Class 2; three to five feet in height, Class 3; five to eight feet in height, and Class 4; eight to twelve feet of vertical erosion. A total of 3,800 linear feet are currently in Class 1; 6,100 linear feet in Class 2; 3,100 linear feet in Class 3, and 1,600 linear feet in Class 4. The extent of the problem is greatest along the points of the eastern shoreline, south of the old railroad grade. Erosion within the embayments of the lake was found to be minimal in nature. The sections that follow describe the general erosion process (Section 6.1), and available erosion protection options, including detailed descriptions of structural and vegetative controls (Section 6.2). Generic plans for stabilizing the Sullivan Lake shoreline are presented in Exhibit 2 and discussed in Section 6.3. The bid package that accompanies this report contains site specific information for two areas of the lake where stabilization work will begin.

6.1 THE EROSION PROCESS

The land-water boundary is characterized by many shapes and configurations. For the purposes of understanding basic shoreline processes and for designing appropriate corrective measures, shorelines can bee classified as either bluffs, cliffs, low erodible plains (including sandy beaches), or wetlands. Many shorelines contain two or more of these basic features. The Sullivan Lake shoreline consists primarily of low to high bluffs.

Cliffs, which are composed of relatively sound rock, rarely undergo severe or sudden erosion. This type of shoreline may experience slow, steady retreat over many years. Such shorelines generally cannot be treated with low cost solutions because available alternatives are usually less durable than the cliff rock itself.

In contrast, bluffs are composed of sediments such as clay, sand, gravel, or erodible rock. Erosion problems are often associated with these kinds of shorelines. The most prevalent causes of bluff erosion are toe scour by wave action, surface runoff, and drainage and infiltration problems that lead to slope stability failures. Wave action on Sullivan Lake is a result of a combination of wind and recreational boating. The impact of wind generated waves is most pronounced on areas of the lakeshore at the end of the fetch, or the distance over which the wind has blown uninterrupted by land. Exhibit 1 shows the fetch line for Sullivan Lake. All of the most severely eroded areas of the lake (eight to 12 feet of vertical erosion) are located at the end of the fetch line.

Erosion problems are most common along bluff shorelines where a variety of forces and processes act together. The most prevalent causes of bluff erosion and recession are scour at the toe (base) by waves and instability of the bluff materials themselves. A brief discussion of factors affecting slope stability and how to recognize potential problems is presented below.

A typical bluff often consists of different soils deposited in distinct layers, such as clay, sand, silt, or glacial till. Soils are not generally stable at a vertical face, but form a slope that varies with the soil and groundwater conditions. Bank slopes are a result of a series of failures whose nature depends on whether the soils are cohesive (clay) or granular (sand, silt, gravel, etc.). Erodibility of the soils is also a key factor. The Sullivan County Soil Survey prepared by the U.S. Department of Agriculture, Soil Conservation Service, (1971) shows that the existing banks of Sullivan Lake are comprised of highly erodible material (Cincinnati silt loams, Ava silt loam, Hickory silt loam). Cohesive soils generally slide along a circular or curved arc, the soil moving downward as it rotates along the failure surface. In contrast, granular soils fail when vertical-sided blocks drop to the bottom or when the soil suddenly flows down an inclined plane. Height is a factor because high bluffs (over 20 feet) impose greater stresses and are likely to suffer more severe stability problems than low bluffs.

The internal strength of soils can be decreased by groundwater and seepage flows within the bluff. Soils, such as coarse sand, which allow rapid and free seepage of water are permeable. Impermeable soils, such as clay, do not allow the free flow of water, allowing seepage only through cracks or other openings. Tree roots and woody vegetation can provide a path for seepage through impermeable soils to layers of greater permeability, accelerating internal erosion of the bluff. Surface runoff combines with internal erosion to erode the face of the bluff, causing gullies and deposits of eroded material on the bench area below. The seepage exiting the bluff near the base can also cause surface erosion.

Wave action at the toe of the bluff is also a major cause of shoreline erosion. Waves sort shoreline sediments, moving clays and silts offshore while leaving more permeable sands and gravels for the beach. During storms, waves can reach the bluff itself and erode or undercut the toe. Depending on the bluff soil characteristics, only a short time may be needed under such conditions for the entire bluff face to fail.

In evaluating conditions at a site, it is necessary to determine which of the above processes is primarily responsible for the erosion problem. Slope stability problems that are not aggravated by toe undercutting should be treated using established civil engineering techniques of slope stability analysis and design. Typical solutions could include vertical or horizontal drains, slope regarding and terracing, surface drainage controls, elimination of unnecessary surcharges at the top of the slope, and buttressing the toe.

Wave action at the toe which undermines the bluff can be treated using a low cost shore protection device. This scenario appears to be the principal cause of erosion to the shoreline of Sullivan Lake. Important factors to consider in selecting a stabilization method include the relative steepness of the offshore bottom slope, and whether a sand beach is present at the base of the bluff. Beaches are often derived from bluff materials that have fallen from above. They provide a buffer against normal wave action and may serve as a suitable foundation for various protective devices.

The slope of the offshore bottom is important to wave action on a bluff. If the offshore slopes are steep, deep water is closer to shore, more severe wave activity is possible, and maintenance of a protective beach is more difficult. In contrast, flat offshore slopes result in shallower water near the shorelines, which inhibit heavy wave action at the bluff and provide for potentially better protective beaches. Existing topographic and bathymetric data, and lake sounding data obtained during this study indicate that the lake bottom adjacent to the majority of eroded bluffs at Sullivan Lake is quite steep. This allows more intense wave action to reach the shoreline. In general, steep slopes near eroded banks limit shoreline protection alternatives to structural methods, such as rip rap or bulkheads. Structural and vegetative stabilization methods require regrading of the banks to a more favorable slope under these conditions.

6.2 AVAILABLE SHORELINE EROSION PROTECTION OPTIONS

Three primary options are available when confronted with an erosion problem: take no action, relocate endangered structures, or take positive action to halt the erosion. The latter includes non-structural techniques, such as vegetative stabilization as well as structural devices that act to armor the shoreline, intercept or diminish wave energy offshore, or retain earth slopes against sliding. Institutional controls, such as implementing boat speed regulations or no-wake zones, are also an option to slow advancing erosion.

Any action taken requires evaluation of the shoreform, current and anticipated land use, funding and time available, and other effects of the decision. Discussed in the following sections are the range of alternatives available to address the erosion problems along the shoreline of Sullivan Lake.

The alternatives presented are referred to as "low cost", however, properly designed and constructed shore protection is not inexpensive. The term "low cost" implies that these measures are commensurate with the value of property being protected and that they are among the lower priced options available. Whether a solution is considered a low cost alternative or not must be weighed against both the actual and aesthetic values of what is being lost to erosion.

6.2.1 No Action

The expense of shoreline protection requires consideration of a no action alternative. Adoption of this alternative must be weighed against the cost of potential loss of property, decrease in property values, and potential decreases in the number of recreational visitors to the lake and to the Sullivan County Park. If the rate of erosion along the shoreline was caused by temporary activities and thus expected to slow, or if only unproductive land or inexpensive structures were threatened, a no action alternative may be appropriate. For Sullivan Lake, this alternative is only recommended as a tool to prioritize available funding.

6.2.2 Relocation

In severe cases of shoreline erosion, physical relocation of endangered structures or facilities to a different area or farther from the water on the same lot should be considered as an alternative solution. This alternative has little applicability for Sullivan Lake. Houses or other structures are not immediately threatened. However, valuable lakefront property with mature trees, docks, and beach areas have been impacted. If, in the future, it does become necessary to move a structure, the effort and costs could be wasted if it is not moved back far enough. Knowledge of the erosion rate (feet/year) and the likelihood that this rate will continue at or below historical levels is critical to determining the distance of the setback. Calculation of erosion rates were beyond the scope of this study.

6.2.3 Institutional Controls

One of the primary causes of erosion of the shoreline of Sullivan Lake is constant attack of the shoreline by boat generated waves and wakes. The low amplitude, high intensity attack by these waves produces constant undercutting of the toes of the bluffs along the shoreline. The effect is most pronounced when boats having large drafts go from a standing position to full speed, as in starting a water skier. Once a full plane is reached, the effect is greatly reduced.

Control of boat generated waves falls under the category of institutional controls. These may range from severe restrictions, such as prohibition of certain horsepower engines, or a ban on engines entirely, to restricting access or speed in certain areas of the lake. Another, more flexible approach is lake zoning, either by time or by space (Wagner, 1990). Time zoning involves establishing certain hours of the day for non-motorized uses, and others for skiing or power boating. Alternation of days for motorized and non-motorized uses is also an example of time zoning. Space zoning involves setting aside certain portions of the lake for specific uses, thus protecting key areas of the lake from motorboat impacts. Implementation of time and space zoning regulations is usually in response to competing recreational uses, such as sailing and waterskiing. For Sullivan Lake, there is no question that power boating is a major attraction, and considerable opposition would be expected to restrictions in their use. Despite anticipated public opposition, some degree of institutional controls is recommended to reduce the impact of boat generated waves to the most severely eroded areas. This could take the form of buoys positioned off of areas where erosion is currently between eight and twelve vertical feet (approximately 1,600 feet of shoreline). The area between the buoys and the lakeshore could be considered a protected area, with access limited to non-motorized craft.

6.2.4 Vegetative Stabilization

The existing eroded shoreline of Sullivan Lake and the lake bottom adjacent to these slopes is, for the most part, fairly steep, and does not provide ideal habitat for vegetative stabilization. However, there is a growing body of literature that supports this alternative over structural methods, even in severely eroded areas with steep slopes. The costs of vegetative stabilization are far less than structural controls. For this reason, and the recently reported success of this method in situations comparable to Sullivan Lake, vegetative stabilization is strongly recommended.

Recommendations from a southern Indiana nursery (Vallonia State Nursery, Vallonia, IN) concerning appropriate types of plants indicate that either willow cuttings or Virginia pine would be good choices. Willows have been used very successfully to stabilize eroded stream banks, and have been shown to be very resistant to the force of flood waters within weeks of planting (Roseboom, 1990). Willow cuttings have also been planted along other eroded lake shorelines in Indiana (Jim Lake, pers. comm.). Virginia pine are often planted along road cuts on extremely steep slopes. These trees are very tolerant of sandy soils and harsh conditions, such as exposed, windy shorelines. The trees are normally planted in the spring at an age of one year. A six foot interval between plantings is recommended. The trees could be planted by themselves or within a rip rap revetment. Given the successful use of willows along streambanks and in riparian areas, preference should be given to this species over Virginia pine in areas closer to the water's edge. A combination may be appropriate in areas higher than eight to ten feet above the water.

Costs for vegetative stabilization are a fraction of the cost for structural controls. If the total length of one to five foot high eroded banks (9,900 linear feet) were planted with small willow cuttings, assuming a single row of planting for the one to three foot areas, and a double row for the three to five foot areas, the cost would be approximately $2,100. This assumes a per cutting cost of $0.33, including labor (Vallonia State Nursery estimate). For Virginia pine, the cost would be approximately $600, assuming one tree every six feet, for a total of 1,650 trees. This is assuming hand planting at a labor cost of $0.25 per tree, plus approximately $.06 per tree ($6.00 per 100 trees). Potential need for fertilizers and access limitations may increase this price. Voluntary labor would reduce the cost of both pine and willow planting by more than 70%. However, regrading of the shoreline to a more favorable slope could significantly increase the costs.

In the Cort Creek watershed in Illinois, willow cuttings have been used to stabilize severely eroded streambanks. Mr. Don Roseboom, Illinois State Water Survey in Peoria, IL, has directed this work and was consulted with regard to erosion along the Sullivan Lake shoreline. For highly eroded areas, his recommendations are to use willow posts, three to five inch diameter willows, along the toe of the eroded banks for maximum protection, particularly along the east-central shore. The posts should be planted six feet deep, and should have a total length of 10 to 12 feet. They should be separated by a distance of four feet. Higher on the banks, smaller diameter cuttings can be used, however native grasses interspersed with the willows are recommended. For sections of streambank with 15 feet of vertical erosion, the Illinois State Water Survey has planted four rows of willow posts, starting just above the water line, in a staggered pattern. Costs for the area planted in this manner were between three and five dollars per linear foot. Willow posts that were planted within days of being cut rooted faster and were generally in better condition following planting. March planting is recommended.

Given the importance of stabilizing the toe of the eroded banks, great care should be taken in planting this area of the slope. A trial planting in a moderately eroded area is recommended to gain experience prior to planting more severely eroded areas. This would allow a number of details to be worked out prior to a full scale operation, such as access limitations, sources and costs of plants, and required labor and equipment. Regrading of the banks to a more moderate slope may be necessary in some areas. A trial planting would help determine if this will be necessary, where possible.

The U.S. Army Corps of Engineers has prepared an evaluation form to determine the applicability of planting certain eroded areas (Figure 17). Use of this form results in a numeric score for a given area of shoreline. The score dictates both the age and spacing of plants, or whether planting is appropriate at all. The form applies generally to wetland plant species, and therefore should serve only as a guide to determine the suitability of a particular site.

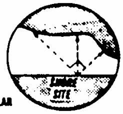
6.2.5 Structural Controls

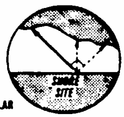
The following section describes structural control methods applicable to the eroded shoreline of Sullivan Lake. Excxept in the most severely eroded areas, application of any of these methods prior to evaluating the results of vegetative techniques is not recommended. Exceptions include the shoreline adjacent to Walls Cemetery, where the proximity of existing graves to the slumped ground in this area raises concern, and the area just south of the main boatramp on the lake. These areas should be protected as soon as possible with structural controls, as described below and in Exhibit 2.

Revetments. A revetment is a heavy facing (armor) on a slope to protect it and the adjacent upland against wave scour. A conceptual design of a revetment for an applicable area of the Sullivan Lake shoreline is presented in Figure 18 and Exhibit 2). Revetments depend on the soil beneath them for support and should, therefore, be built only on stable shores or bank slopes. Slopes steeper than 1 on 1.5 (1 vertical on 1.5 horizontal) are unsuitable for revetments unless flattened. Fill material, when required to achieve a uniform slope, must be properly compacted.

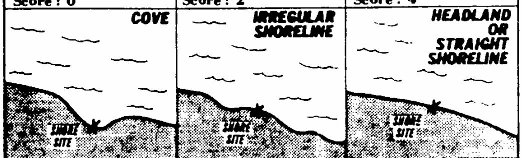
Revetments protect only the land immediately behind them and provide no protection to adjacent areas. Erosion may continue on adjacent shores and may be accelerated near the revetment by wave reflection from the structure, although not as seriously as with vertical-faced bulkheads. Revetments are not recommended on areas of the shoreline with greater than five feet of vertical erosion.

1. SHORE VARIABLES	2. DESCRIPTIVE CATEGORIES (SCORE AS INDICATED)						3. SCORE
a. FETCH - AVERAGE AVERAGE DISTANCE IN KILOMETERS (MILES) OF OPEN WATER MEASURED PERPENDICULAR TO THE SHORE AND 45° EITHER SIDE OF PERPENDICULAR	Score : 0 LESS THAN 3.0 (1.8)	Score : 2 3.1 (1.9) to 6.0 (3.7)	Score : 4 6.1 (3.8) to 9.0 (5.6)	Score : 6 9.1 (5.7) to 12.0 (7.5)	Score : 8 12.1 (7.6) to 15.0 (9.4)	Score : 10 GREATER THAN 15.0 (9.4)	
b. FETCH - LONGEST LONGEST DISTANCE IN KILOMETERS (MILES) OF OPEN WATER MEASURED PERPENDICULAR TO THE SHORE OR 45° EITHER SIDE OF PERPENDICULAR	Score : 0 LESS THAN 4.0 (2.5)	Score : 2 4.1 (2.6) to 8.0 (5.0)	Score : 4 8.1 (5.1) to 12.0 (7.5)	Score : 6 12.1 (7.6) to 16.0 (10.0)	Score : 8 16.1 (10.1) to 20.0 (12.6)	Score : 10 GREATER THAN 20.0 (12.6)	

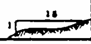




1. SHORE VARIABLES	Score : 0	Score : 2	Score : 4	3. SCORE
c. SHORELINE GEOMETRY GENERAL SHAPE OF THE SHORELINE AT THE POINT OF INTEREST PLUS 200 METERS (660 FT) ON EITHER SIDE	COVE	IRREGULAR SHORELINE	HEADLAND OR STRAIGHT SHORELINE	



1. SHORE VARIABLES	Score : 0	Score : 4	3. SCORE
d. SHORE SLOPE SLOPE OF THE PLANTING AREA (VERTICAL TO HORIZONTAL)	GRADUAL 1 to 15 OR LESS	STEEP MORE THAN 1 to 15	



1. SHORE VARIABLES	Score : 0	Score : 2	Score : 4	Score : 6	Score : 8	3. SCORE
e. SEDIMENT GRAIN SIZE OF SEDIMENTS	SILT & CLAY	FINE SAND	MEDIUM SAND	COARSE SAND	GRAVEL	

1. SHORE VARIABLES	Score : 0	Score : 8	Score : 16	3. SCORE
f. BOAT TRAFFIC PROXIMITY OF SITE TO NAVIGATION CHANNELS FOR LARGE VESSELS OR SMALL RECREATIONAL CRAFT	NO NAVIGATION CHANNEL WITHIN 1 KILOMETER (0.6 MILES)	NAVIGATION CHANNEL WITHIN 1 KILOMETER (0.6 MILES)	NAVIGATION CHANNEL WITHIN 100 METERS (330 FT)	

1. SHORE VARIABLES	Score : 0	Score : 4	Score : 8	3. SCORE
g. WIND THE ORIENTATION OF THE SITE IN RELATION TO LOCAL WINDS	SHELTERED FROM WIND	DOES NOT FACE IN THE DIRECTION OF PREVAILING WINDS OR FREQUENT STORM WINDS	FACES IN THE DIRECTION OF PREVAILING WINDS OR FREQUENT STORM WINDS	

4. CUMULATIVE WAVE CLIMATE SCORE ____

```
SCORE =  1 TO 10:  USE SPRIGS AT 3-FOOT SPACINGS IN 10-FOOT
                   (MINIMUM) ZONES.
      = 11 TO 20:  USE SPRIGS OR 15-WEEK SEEDLINGS AT 1½-FOOT
                   SPACINGS IN 10-FOOT (MINIMUM) ZONES.
      = 21 TO 30:  USE 5-7 MONTH SEEDLINGS OR PLUGS AT 1½-FOOT
                   SPACINGS IN 20-FOOT (MINIMUM) ZONES.
      = ABOVE 30:  DO NOT PLANT
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Figure 17. Site evaluation form for marsh plants (after U.S. Army Corps of Engineers (1990)).

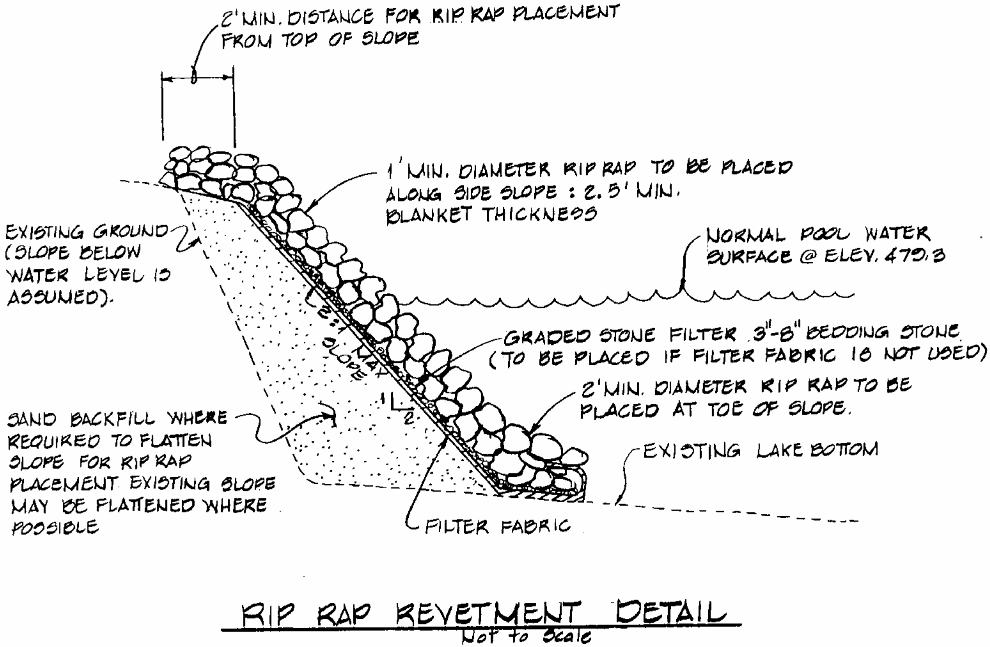

Figure 18. RIP rap reventment detail.

Of the revetment's three components, the primary one, which determines the characteristics of the other two, is the armor layer (which must be stable against movement by waves). The second component, the underlying filter layer, supports the armor against settlement, allows groundwater drainage through the structure, and prevents the soil beneath from being washed through the armor by waves or groundwater seepage. The third component, toe protection, prevents a settlement or removal of the revetment's lakeward edge.

Overtopping wave action which may erode the top of the revetment can be limited by a structure height greater than the expected maximum wave height, or by protecting the land at the top of the revetment with an overtopping apron. Flanking, a potential problem with revetments, can be prevented by tying each end into adjacent shore protection structures or the existing bank. As the bank retreats, however, the ends must periodically be extended to maintain contact.

The armor layer of a revetment maintains its position under wave action either through the weight of, or interlocking between, the individual units. Revetments are either flexible, semi-rigid, or rigid. Flexible armor retains its protective qualities even with severe distortion, such as when the underlying soil settles or scour causes the toe of the revetment to sink. Quarrystone, rip-rap, and gabions are examples of flexible armor. A semi-rigid armor layer, such as interlocking concrete blocks, can tolerate minor distortion, but the blocks may be displaced if moved too far to remain locked to surrounding units. Once one unit is completely displaced, such revetments have little reserve strength and generally continue to lose units (unravel) until complete failure occurs. Rigid structures may be damaged and fail completely if subjected to differential settlement or loss of support by underlying soil. Grout-filled mattresses of synthetic fabric and reinforced concrete slabs are examples of rigid structures.

Most of the areas where revetments would be applicable are located along the western shorelines (see Exhibit 1) where erosion has not progressed to a significant degree. Topography in this area indicates that slopes beneath the normal pool level are somewhat flatter than those along the eastern shoreline. It also appears that some of the areas would be accessible by land, which would allow construction access in order to flatten existing slopes to the extent possible.

Revetment Costs. Based upon cost data provided by Rogers Stone in Bloomington, IN, the cost of Indiana Department of Transportation revetment grade rip-rap delivered to Sullivan Lake is approximately \$10.50 per ton. The average diameter of this material is nine inches, and it would be suitable for protection of all moderately eroded areas. The estimated cost of rip-rap construction near the main boat ramp was approximately \$32,000. This included delivered and installed costs for the rip-rap along the approximately 700 foot section of shoreline (six vertical feet of protection at a thickness of 18 inches), installation of geotextile fabric, and excavation to the required 3:1 grade. Planting of eroded areas above the rip-rap section would be in additon to this cost. Cross-sectional areas and volumes of fill material that may be necessary must be determined prior to estimating costs for other areas of the shoreline.

Bulkheads. A bulkhead is essentially a retaining wall, whose primary purpose is to hold or prevent sliding of the soil and to provide protection from wave action by preventing undercutting of the slopes' toe. Bulkheads may be employed to protect eroding bluffs by retaining soil at the toe, thereby increasing stability, or by protecting the toe from erosion and undercutting. Bulkheads are also used for reclamation projects where a fill is needed at a position in advance of the existing shore. Bulkheads are far more applicable as a shore erosion device than a revetment in those areas where the lake bottom is steep, because they can be driven into the lake bottom and do not require a flat bottom for stability. An example of generalized bulkhead showing design criteria are shown in Exhibit 2.
Construction of a bulkhead does not insure stability of a bluff. If a bulkhead is placed at the toe of a high bluff steepened by erosion to the point of incipient failure, the bluff above the bulkhead may slide, burying the structure or moving it toward the water. To increase the chances of success, the bulkhead should be placed somewhat away from the bluff toe, and if possible, the bluff should be graded to a flatter, more stable slope.

Bulkheads may be either thin structures penetrating deep into the ground (e.g., sheet piling) or massive structures resting on the surface (e.g., sand-or grout-filled bags). Sheet pile bulkheads require adequate ground penetration to retain soil. Stacked bag structures do not require heavy pile-driving equipment and are appropriate where subsurface conditions hinder pile penetration. However, they need firm foundation soils to adequately support their weight. Because they do not generally penetrate the soil, stacked type bulkheads often cannot prevent slides where failure occurs beneath the surface. This limits their effectiveness to sites where the backfill and structure are low.

Bulkheads protect only the land immediately behind them and offer no protection to adjacent areas up and down the shoreline or to the fronting beach. In fact, because bulkheads normally have vertical faces, wave reflections are maximized, wave heights and overtopping may increase, and scour in front of the structure is more likely. In addition, if downdrift beaches were previously nourished by the erosion of land now protected, they may erode even more quickly. Since scour at the toe of the bulkhead can be a serious problem, protection of the base is necessary for stability. Typical toe protection consists of quarrystone large enough to resist movement by wave forces, with an underlying layer of granular material or filter cloth to prevent the soil from being washed through voids in the scour apron. Flanking (erosion of the shore around the ends of the structure) can also be a problem. This can be prevented by tying each end into existing shore protection devices or the bank. The following paragraphs discuss several types of bulkheads that would be applicable to the Sullivan Lake shoreline.

Sheet Pile Bulkheads. Sheet pile bulkheads consist of interconnecting or very tightly spaced sheets of material driven vertically into the ground with special pile-driving equipment. The sheeting can be made of steel, aluminum, or timber. Sheet pile structures may be either cantilevered or anchored.

A cantilever bulkhead is a sheet pile wall supported solely by ground penetration, making it susceptible to failure from toe scour. The sheet piling must be driven deep enough to resist overturning, which usually requires penetration to a depth two to three times the free standing height, including the anticipated scour depth (usually about one wave height).

An anchored or braced bulkhead is similar to a cantilever structure, but gains additional support against seaward deflection from embedded anchors or tilted structural bracing on the seaward side. For this structure, the piles generally only need to be embedded to a depth one and one-half to two times the heights of the wall above the anticipated scour depth. Anchors are usually a row of piles or line of heavy objects (deadmen) with a large surface area driven or buried a distance behind the bulkhead. Connections between pile anchors or deadmen and the wall should be wrought iron, galvanized, or other corrosion-resistant steel. Plain carbon steel should not be used for long-term protection. Horizontal wales at or near the top of the wall laterally distribute the anchor loads. Anchor systems are not well suited to sites with buildings close to the shoreline because of the distance needed between the bulkhead and anchors. In that case, brace piles may be used in place of anchors.

The type of soil at a site determines the type of sheet piling that can be used. Steel sheet piling can be driven into hard soil and some soft rock. Aluminum and timber sheet piling can be driven or jetted into softer soil. An analysis is required to determine the subsurface conditions at a site and should be performed prior to selection of materials.

The advantages of sheet pile bulkheads are their long and relatively maintenance-free life and their uniform appearance. Their disadvantages include the special pile-driving equipment and trained operators required to install them.

Treated Timber. Well designed and built timber structures have long been recognized as viable and economical for bulkhead construction. Examples of treated timber bulkheads are shown in Figure 19 and Exhibit 2.

Only specially treated timber should be used to prevent deterioration. The joints between sheets should be kept as tight as possible and filter fabric should be used as an added precaution against loss of the soil through cracks. Only granular material should be used for backfill. Supplemental drain holes should be placed at regular intervals to further facilitate movement of water from behind the structure and these must always be backed with filter cloth or crushed stone filters. All hardware and fasteners should be corrosion-resistant or protected metal. In addition, washers should be provided under all bolts and nuts to insure that these bear evenly on the timber members.

Steel. Steel sheet piling is probably the most widely used bulkhead material. The interlocking feature of sheet pile sections provides a sand-tight fit, generally precluding the need for filters. The close fit may also be essentially water-tight, so regularly spaced weep holes are recommended. These, and lifting holes in the piling, should be backed with graded stone filters or filter fabric to prevent loss of backfill.

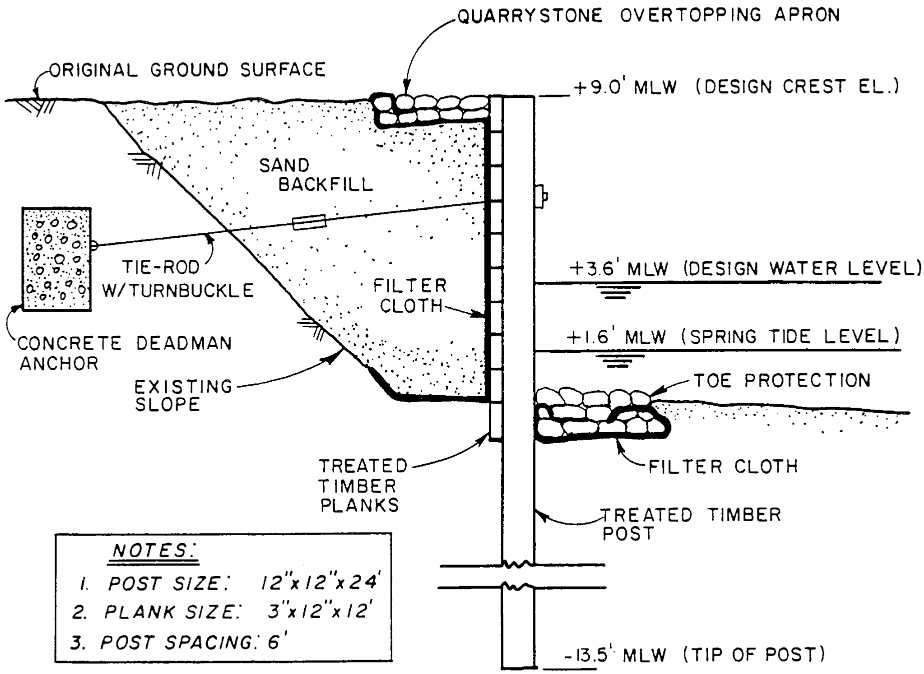

Figure 19. Treated timber bulkhead.

Aluminum. Aluminum sheet piling is designed and installed using conventional methods and equipment. Its primary advantages over steel are lighter weight and superior corrosion resistance. Individual sheets can be carried and maneuvered by one man, and most drilling and cutting can be performed with simple hand tools. Its main disadvantage, compared to steel, is less ruggedness when driven, so it usually cannot penetrate logs, rocks, or other hard obstructions.

Bulkhead Costs. Bulkhead costs typically vary from $150.00 to $250.00 per linear foot of bulkhead for typical 15' length wood bulkheads. The cost may increase to $400 per linear foot for aluminum sheet pile bulkhead. Bulkhead construction would be applicable for Sullivan Lake where bank erosion is greater than five feet in height. Approximately 4,700 feet of shoreline are in this condition. Assuming bulkhead construction along all 4,700 feet, the costs would range between $705,000 and $1,175,000. These areas are located predominantly along the eastern shoreline of the lake. The costs for bulkhead construction along only the most severely eroded areas, the 1,600 feet of eight to twelve foot high eroded banks, would range between $240,000 and $400,000. The costs would probably be near the high end of this range due to access limitations and the need to remove trees that have already been undermined by slope failure. Due to the height and steepness of the existing shoreline in this area, coupled with the accessibility constraint, it is not recommended that flattening of the existing slopes be attempted. Bulkhead construction would be accomplished by means of transporting and installing construction material by barge to the extent possible.

Bulkhead Design. The wave design height used to determine the minimum height of the bulkhead above the normal pool elevation was determined based upon the following criteria:

- Predominant wind direction is from the northwest for a design condition return period = 25 years,
- wind speed = 80mph (Figure 20)
- average water depth = 11 feet (from bathymetry)
  use average depth = 15 feet
- fetch length = 6,500 feet = 1.23 miles (from Exhibit 1)
  use fetch length = 1.5 miles

According to specifications contained in Table 1, Low Cost Shore Protection, the design wave height for bulkhead construction should be 4 feet. For long term shore protection, conservative assumptions have been used from the referenced publication in order to determine the maximum wave height, which sets the elevation at the top of the bulkhead. Since severe waves breaking against the bulkhead will run up to an elevation higher than its crest, (under the design condition) it is necessary to provide a splash apron to avoid backfill and bank erosion, if the structures are overtopped. If the apron were not provided, it would be necessary to elevate the wall considerably in order to ensure that the wall would not be overtopped from wave action, increasing costs substantially over the splash apron.

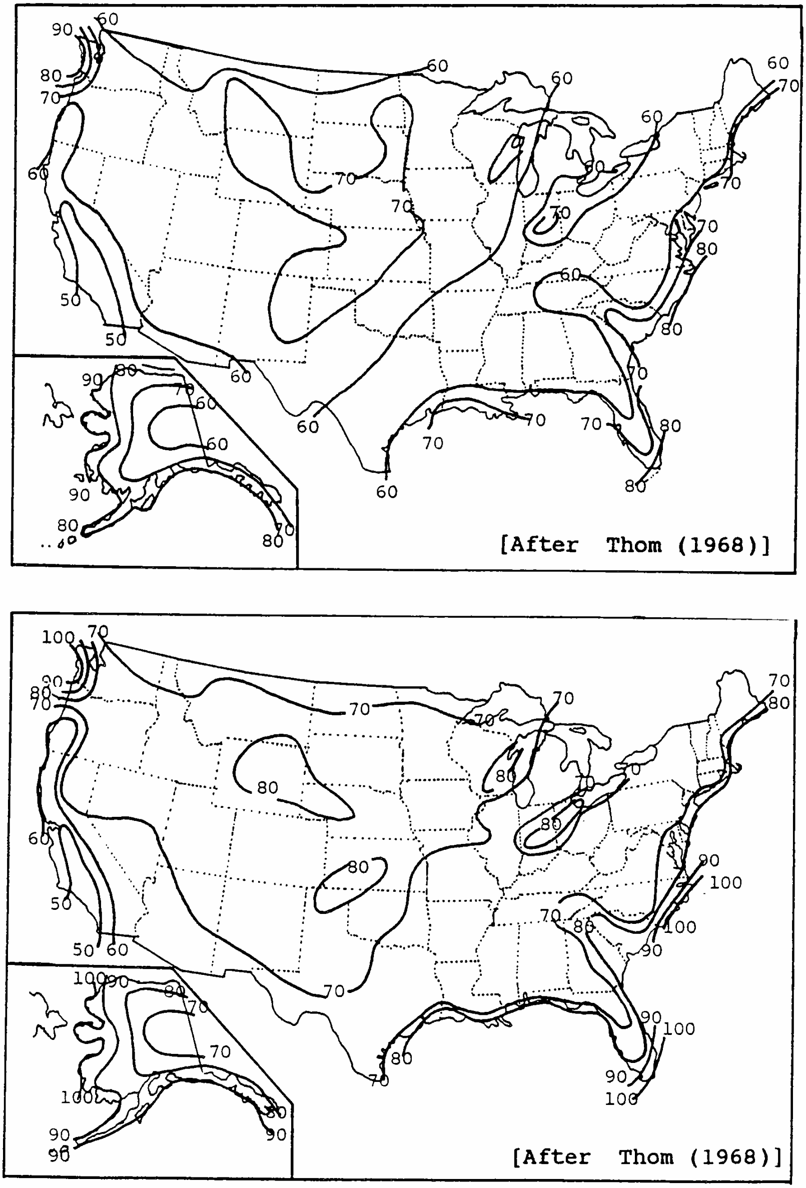

Figure 20. Fastest-mile wind speeds: 10- and 25-year (respectively) return period.

The bulkhead plan view shown in Exhibit 2 depicts the necessity for construction of return walls. These walls should be keyed into the existing shorelines at each end of the area where bulkhead protection is provided. Construction of the return walls will protect against breaking waves causing shore retreat and subsequent erosion and slope failure of the retained earth behind the structure.

6.3 REQUIRED PERMITS FOR SHORELINE STABILIZATION

Discussion with the U.S. Army Corps of Engineers, Louisville District, and the Indiana Department of Natural Resources indicates that an IDNR Construction in a Floodway Permit and a U.S Army Corps of Engineers Section 404 permit will be required if any degree of sediment removal, such as for backfilling bulkheads, or regrading of steep slopes, is required. Filing and review of a 404 Permit takes approximately 60 days. Small rip-rap projects (less than one cubic yard of rip-rap per running foot up to 500 linear feet) fall under a Corps of Engineers Nationwide Permit, and thus do not require a 404 Permit. However, any excavation below the normal pool elevation, such as work that would be required to regrade slopes for rip-rap or to plant vegetation, requires a 404 permit. The Sullivan Lake Park and Recreation District is strongly advised to discuss all planned stabilization measures with the Louisville District Corps to determine what permits will be required. The fine for construction without a proper permit is $25,000 per day per violation, until the affecting structure(s) is removed. Filing a 404 Permit results in a public notice of the proposed activity, which is distributed by the Corps to affected landowners and other interested parties. The public has a 30 day period during which they can comment on the project. Plans and a description of the project must be submitted with a 404 application. The information submitted for the Design component of this project will be more than sufficient to complete the application. Inquiries and permit requests should be directed to the Louisville District office at the following address:

Mrs. Pat Rucker
U.S. Army Corps of Engineers
Operations and Readiness Division
P.O. Box 59
Louisville, Kentucky 40201
(502) 582-5607

Information on the Construction in a Floodway Permit, issued by the Indiana Department of Natural Resources, Division of Water, can be obtained by contacting the Division of Water at the following address:

Mr. Brian Balsley
IDNR Division of Water
2475 Directors Row
Indianapolis, IN 46241
(317) 232-5661

Copies of the applications for these permits are included in the Bid Package submitted with this report. Sullivan County should also be contacted concerning any locally required permits.

6.4 SUMMARY OF RECOMMENDATIONS FOR SHORELINE PROTECTION

Based upon data collected during this study, and similar studies reported in the literature, vegetative stabilization is recommended as the primary shoreline protection method. If this method proves unsuccessful following the first year of planting, regrading of steeper slopes and replanting, and/or installation of rock revetments and wood bulkheads offer practical solutions to control undercutting of the bluff faces and subsequent collapse and erosion. In addition, an institutional component, involving placement of buoys along the most severely eroded areas, is recommended. These buoys should be placed no farther than 150 feet from shore. The protected area should include the entire length of shore in which erosion is between eight and twelve feet in height (see Exhibit 2). Placement of the buoys should be done as soon as possible. Also, a handout should be developed that would describe the erosion problem at Sullivan Lake, and the corrective measures that will be applied. This could be given to park visitors at the entrance.

The costs of all techniques addressed in this study increase substantially in the following ascending order:

- Lake regulations
- Placement of speed or access limiting buoys
- Vegetative Stabilization
- Regrading and Vegetative Stabilization
- Stone revetment (rip rap)
- Wood bulkhead (non-cantilevered)
- Steel bulkhead
- Aluminum bulkhead.

The costs incurred for shoreline protection will be dictated by the priority assigned to the various segments of shoreline that need protection. The four classes of erosion severity that were identified during this study are intended to facilitate a ranking process. However, high priority should be given to the shoreline adjacent to the main boat-ramp and near Walls Cemetery. Ground slumping and tree loss are occurring in these areas. Near the cemetery, the proximity of existing graves with respect to the lake shoreline raises particular concern. However, the degree of erosion is greater near the boat-ramp. Work in this area would be readily seen by visitors to the lake, which would increase public understanding of the problem. This will be particularly important for institutional controls, such as buoy placement, to be effective.

The Sullivan County Soil Conservation Service (SCS) should be consulted on all future activities that relate to shoreline stabilization. The SWCD District Conservationist, Mr. Jeff Coats, has willingly assisted in various aspects of this Feasibility Study. The SWCD will be able to further assist the Sullivan County Park and Recreation District in planning and obtaining funding for construction activities.

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SECTION 7. SUMMARY AND RECOMMENDATIONS

Based on the watershed analysis, lake and tributary sampling, and shoreline surveys, existing conditions and recommendations for Sullivan Lake and its watershed can be summarized as follows:

- The main body of the reservoir is relatively healthy, in terms of water quality. Water column profile measurements, biological measurements, and laboratory results of water samples all show that Sullivan Lake is in good condition relative to other midwestern lakes in agricultural areas. The lake is moderately eutrophic. No recommendations are made at this time for implementation of in-lake restoration activities.

- Application of the Agricultural Non-Point Source Pollution (AGNPS) model to the Sullivan Lake watershed showed that the wetland at the north end of the reservoir is critical in trapping sediments and nutrients. The wetland filters runoff from the Morrison Creek sub-basin (50% of the watershed area), significantly reducing sediment bound nutrients and the sediment load itself in runoff from this sub-basin.

- 14,600 linear feet of the Sullivan Lake shoreline (2.8 miles) are currently in an eroded condition. The erosion is most extensive along the eastern shore in the central part of the lake, where the effect of wind generated waves is greatest. Erosion in excess of eight vertical feet was found along 1,600 feet of shoreline in this area. Eroding banks in the vicinity of the main boat ramp and at Walls Cemetery are of particular concern. These areas should be protected with rip-rap, a timber bulkhead, or similar structural control in the near future.

- For the majority of the remaining shoreline, vegetative methods are recommended as the primary means of shoreline protection. Willow posts (three to five inch diameter) at the base of eroded banks and on the entire face of the most severely eroded area along the eastern shore is recommended. A combination of smaller diameter willows and native grasses should be used in other areas. Virginia pine trees have also been used effectively for shoreline protection.

- Structural shoreline protection methods (revetments, bulkheads) will be costly given the magnitude of the erosion problem at Sullivan Lake. Should vegetative stabilization fail, these techniques will be required.

- In addition to vegetative controls, placement of buoys along the most severely eroded shorelines is strongly recommended. Boat generated waves are a constant threat to bank stability, particularly in areas of the lakeshore that receive the brunt of wind generated waves.

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SECTION 8. REFERENCES

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EXHIBITS

Two exhibits are enclosed in this report. Exhibit 1, Plan of Existing Bank Erosion, is drawn at a scale of 1:400. Exhibit 2, Shore Protection Details, is a series of drawings, not drawn to scale, that show generic designs for vegetative and structural shore protection controls. The two exhibits are not intended to serve as engineering plans for specific sites on the lakeshore. However, they will be important references for future shoreline protection efforts.

The Exhibits are large engineering drawings that cannot be scanned and are not on the on-line version of this document.